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A BRIEF REVIEW OF THE MINING INDUSTRY OF MEXICO.

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(TRANSLATED BY J. F. KEMP.)

Mexico possesses a physiographic outline so characteristic and so generally familiar that it need not be described at length in an article like the present. It is sufficient to remind the reader that it is the tapering southern end of North America, terminating itself in an isthmus and having two peninsulas, one projecting into the Gulf of Mexico, the "American Mediterranean"—and the other separating the Gulf of California from the Pacific Ocean. The larger portion of its area and the one forming its central part from the boundaries with the United States southward, is a great plateau which is cut off from the llanos of Texas by the Rio Grande del Norte. This great plateau rises gradually as one goes south and southeast, as far as north latitude 19° 31′. The surface of the plateau is broken by two great groups of mountain ranges, with a depression between which is itself blocked out by many spurs. The two great mountain systems tend to unite toward the south, and the depression between them is largely filled by detritus from the ranges. Especially in the southern regions vast volcanic flows and deposits of tuffs have contributed to the same result, and indeed are chiefly responsible for the present altitude of the surface. This combination of mountain and plateau is known among the Mexicans

as "Sierras Madres y la Mesa Central," yet they constitute a physiographic unit. The present outline has been in part produced by block faults of extraordinary length and in part by the huge piles of volcanic ejectments. We find deep valleys as well as lofty cones.

Outside of the relatively limited areas of the Archean and Paleozoic formations which appear in the coastal regions along the Pacific, fronting the great ocean in Sonora and Lower California, all the rest of the country consists of the following: Mesozoic sediments, chiefly Cretaceous; Tertiary eruptions, both plutonic and volcanic, and detrital rocks derived from all the above. The Mesozoic strata occupy all the eastern part of the country, beginning with the edge of the coastal plain. They constitute as well the eastern system of the Sierra Madre, many of the interior ranges, and extend to the western edge of the great tableland. The Tertiary eruptives are, however, the chief contributors to the great mountain system of the western Sierra Madre.

The stratigraphic upheavals are chiefly due to the meridional movements in the crust of the globe, which occurred at the commencement of the Tertiary, and which chiefly manifested themselves in a great network of faults. These movements were accompanied by the entrance of great masses of intrusive rocks. They were followed at the close of the Miocene by the vast outbreaks of effusives which have continued until the present time, and which have built up on the table land the series of volcanic mountains now forming the Sierra Madre Occidental; the cones, flows and tuffs of the southern plateau, and the great eruptive area which extends to the Sierra Madre del Sud.

The extraordinary mineral wealth of Mexico bears a close genetic relation with the intensity of the intrusive and effusive outbreaks of the Tertiary. The general condition of the ore deposits compels us to believe that this relation is well established and that the influence, especially of the intrusive rocks, is demonstrated in the most positive manner. Indeed as the result of the intense erosion and of the breaks and stratigraphic upheavals the intrusive rocks now appear at the surface in a great variety

of species, both in the Sierra Madre Oriental and in the interior of the Mesa Central. The mineral deposits in this part of the country occur along the eruptive contacts and display many contrasted characters, both in their relations to the wall rocks and in mineral composition. In these same regions, moreover, when the eruptive rocks have not been exposed for investigation the ore-bodies take on the form of replacements in limestones, or else fill great, preëxisting cavities in these rocks where they have been deposited by the uprising waters.

On the other hand, in the Sierra Madre Occidental the greater number of mineral deposits are true fissure veins, with walls of Tertiary eruptives, among which andesites, porphyrites, dacites and their breccias and tuffs are commonest. One may not say that these contrasted types are absolutely sharp in their distribution, nor can it be stated that no contact deposits appear in the Sierra Madre Occidental nor fissure veins in the eastern ranges, yet the contrasts, taken in the large way, do hold. On the south where the mountain systems come together, both types occur.

While the writer does not attempt to make a detailed classification of the mineral deposits of Mexico, yet the following six types include all the great producers of gold, silver, copper, lead, zinc, antimony and tin, with the possible exception of the last-named, which quite often appears segregated in veins in very recent porphyritic rocks.

1. Veins in more or less propylitized eruptives (andesites, dacites, porphyrites, etc.). Under this heading belong the greater number of the deposits of the Sierra Madre Occidental and some on the Mesa Central. Excellent illustrations are furnished by Pachuca, Huatla, Anguangneo and Parral. Sulphides of silver are the chief ore and the gangue is mainly quartz and calcite. Gold is sometimes the principal metal. The silver is always accompanied by sulphides of other metals such as lead, copper and zinc.

2. True veins between walls of clastic rocks which have been metamorphosed by intrusives, and both of which have been faulted by tectonic movements before the introduction of the vein-filling. These deposits are frequent in the central part of

Mexico, such as Taxco, Zacualpan, Sultepec, Tlalpujalma, Providencia, Guanajuato and Zacatecas. Silver is the principal metal produced, but, as in type No. 1, it is often associated with gold and other metals named.

3. True veins with quartz gangue, occurring solely in thinly stratified clastics, and without certainly demonstrated connection with intrusive rocks, even if in the immediate vicinity of eruptives. They are frequent in the central part of Mexico, and good illustrations are El Oro, Pozos and Temascaltepec.

4. Segregated veins in effusive rocks and even at times in intrusives. The best illustrations are furnished by the deposits of tin and a few of iron.

5. Contact deposits between limestones or clastics and intrusive rocks such as granites, monzonites, diorites and different varieties of porphyries. The intrusives sometimes cut across the stratification, again are laccoliths, or they may form the axial core of long ranges of Cretaceous sediments. At other times the mineral deposits appear in connection with dikes, not only in Mesozoic limestones but also in the Archean and Paleozoic strata of the southern and the neorthwestern portions of Mexico. These contact deposits are the chief producers of copper and iron in Mexico. The great copper mines at Cananea belong to this group, as well as most of the ore-bodies in the Sierra Madre Occidental, and of the interior and northern portions of the Mesa Central. While the larger portions of these deposits yield copper or iron, yet there do not fail those with lead or zinc, or even of gold in association with copper. Good illustrations are furnished by San Carlos in Tamaulipas, Sierra del Carmen, Golondrinas, Mazapil, Encarnacion, Las Vegas, Aurora, Balsas, Cerro de San Pedro, Campo Morado, and many more.

6. Deposits in cavities or caves in limestone and replacements in limestone, with or without connection with intrusive rocks. This group embraces all the important ore-bodies yielding lead, zinc, antimony and mercury and a few with copper. Illustrations are provided by Norias, San Juan de Guadalupe, Sierra Mojada, Santa Eulalia, Naica, Amoles, Zinopan and others.

The limits of this paper will not permit the description of other

rarer types, and indeed there are few of importance. For the same reason the importance of faults in localizing values and the influence of secondary enrichment are passed by.

The surprising mineral wealth of Mexico has influenced in the past, and always will influence in the future, the destinies of the country. Mining is the nation's principal industry, and the great amount of capital invested in it, and the vast army of laborers employed in the mines, are actually distributed in 450 different localities spread over the entire country except the coastal plain.

For the slow and safe development of the industry Nature has generously provided the means of subsistence for the laborers, and has made the great area well adapted to the comfortable habitation of man. The coastal regions must be drained and must be made habitable by modern methods in order that a larger number of men may resist the influences of the tropical climate. The sixth part of the Mesa Central is a semi-desert, lacking rain, and very poor in vegetation. So far as agriculture is concerned it contributes little to the sustenance of the country. It is indeed true that cattle are raised in these areas, but nevertheless they are not well adapted to the breeding and improvement of stock, and when the pastures are dried up and the rains fail, as is frequently the case, hundreds of thousands of animals perish. The government has already taken up this matter and has recently appropriated a goodly sum for the promotion of irrigation, the construction of reservoirs, the opening of wells and the acclimatization of fodder plants.

Since the conquest of the country by the Spaniards Mexico has been a great producer of silver and, more than any other nation, up to the middle of the past century had influenced the relations of this metal to the affairs of the world. Besides the great shipments of the refined metal which were made to private owners and as contributions to the crown of Spain, the mints of Mexico coined for domestic use and for shipment to the Far East up to the end of the past century more than 3,000,000,000 ounces of silver.

In order to render possible so large a production within three centuries it was necessary to have the great bonanzas, which are

now indicated by the numerous and enormous workings of the early miners. It was also essential that the operators have at hand both low priced labor, which as a matter of fact differed but slightly from slavery, and a method of extraction well suited to the conditions. The discovery of the patio process by Bartolomeo de Medina, forty-five years after the conquest met these requirements, and the process itself, the foundation of various wet methods in use until recent years, was very well adapted to the treatment of the ores which occur in the upper zone of the deposits where they are suited to amalgamation.

This situation, maintained so long despite the numerous political upheavals, became rapidly and favorably changed by the extraordinary development of natural resources in the western United States where there suddenly sprang up a rival of Mexico as a producer of silver. In this region the milling appliances were perfected and multiplied; the old patio treatment of Medina was shortened and brought under better control and modern methods of smelting were made available. The Mexican government facilitated the introduction of these improvements and gave liberal concessions for the construction of railways from the United States boundary to the City of Mexico and ramifying through the Central Plateau. These lines of transportation made possible the introduction of modern machinery, the importation of fuel which was lacking in Mexico; the opening of new mining districts either on or near the railway, and the exportation northward of a large part of the ores.

To this era of profitable operation succeeded another no less advantageous. Laws were passed in the United States putting a heavy tariff upon imported ores of lead. They led, as an inevitable result, to the construction of great smelting plants in Mexico, and to the creation of powerful companies both for the operation of the furnaces and for the purchase of mines. The improved conditions brought about the opening of new mining districts and brought also within the range of profitable treatment many ores whose assays had hitherto been too low. Whereas, before, silver had been the chief output, now lead and gold were both produced.

This happy situation was still further improved by the sudden rise in price of copper and zinc. Many deposits of copper ores had indeed been long exploited on a small scale, more often for gold than for the red metal. Immense deposits of zinc either abandoned, or at the time unknown, existed in the northern portion of the country; thus with the development of many copper mines and above all of Cananea, Mexico advanced to the position of the second producer of copper among the nations of the world, being exceeded only by the United States. Its absolute yield was about one twelfth the world's total.

Finally as the antimony mines of Japan began to show impoverishment, together with other producers in different parts of the globe, the English syndicate controlling this metal drew from Mexico the larger part of their annual production.

Thus, then, the metals which are actually produced in Mexico for exportation are the following: silver, gold, copper, lead, zinc and antimony. For domestic consumption and in very limited amounts the country also yields iron, quicksilver and tin. The statistics for the year 1906–07, which are a close approximation to the truth are:

Gold	27,770 kilos or	892,825 ounces.
Silver	1,801,700 kilos or	57,925,916 ounces.
Copper	51,655,000 kilos or	113,879,646 pounds.
Lead	70,000,000 kilos or	154,323,400 pounds.

Zinc ores of assay from 20–60 per cent. 100,000 metric tons. These amounts represent an approximate value of $73,000,000 gold ($146,000,000 Mexican), or 14,500,000 pounds sterling. They speak eloquently regarding the importance and prosperity of the mining industry of Mexico.

Only in the yield of silver does Mexico occupy the first position among the world's producers. In order to impart an idea which may be easily retained in the memory we may say that, if the production were uniformly distributed over the entire area of the country, each square kilometer would afford annually about one kilogram of refined silver.

In order to reach these important results Mexico has needed

foreign capital, since, economically considered, the country is not wealthy. The local capital is almost entirely required for the operation and extension of agricultural and urban enterprises, and for the development of the smaller industries. Mexico's greatest wealth lies in its soil. One could hardly state that the Mexican capital invested in the mining industry is small, since some large enterprises belong to Mexican owners, yet the greater number are of restricted size and the Mexicans are occupied rather in prospecting and opening up properties for sale to foreign capitalists than in actual operation. Foreign capital, on the other hand, is rarely used for prospecting. The Mexicans thus perform the meritorious service of preparing the mining properties for future development on a larger scale by foreign capital. As a result the funds brought in from abroad have been in later years employed in establishing enterprises on a solid basis rather than in speculations and in ventures which are more or less gambles.

This secure basis of affairs has led to the development of the cyanide industry which aims to treat those ores of silver and gold which were too low in grade for earlier processes and which largely remain as fillings in old stopes, or as dumps upon the surface. Fortunately these ores almost always consist of sulphides of silver in a quartz gangue, and come under the first three of the types enumerated above. Cyanidation is the great desideratum for the mines of the Sierra Madre Occidental in which are situated about a third of all the mining districts of Mexico. It is toward these that the current of foreign investment is chiefly flowing today, and for their treatment the greater number of new plants are being erected. Nevertheless they are on a comparatively small scale because of the lack of means of transportation. While the State of Chihuahua has been most favored thus far in the construction of railways which penetrate the Sierra, yet there are many opportunities in Sonora, Sinaloa, Durango, Tepic, Jalisco and Oaxaca which only await the introduction of the new methods of metallurgical treatment and concentration now brought to so great a degree of perfection.

Now that the cyaniding of low-grade silver ores has been

proved to be a success, and the advantages afforded by old fillings and dumps as regards cheap mining have been appreciated, it is natural that investors should prefer to acquire properties with great records of production behind them. Hence it is that the application of this method, and the establishment of modern mills have found their most extended fields in Pachuca, Guanajuato, La Luz, Hostotipaquillo and many other old and reliable camps in the Sierra Madre.

In the evolution of the present system of laws governing mining from the ancient codes, the authorities have exercised great care to insure sound titles and to facilitate the prompt and thoroughly legal transfer of ownerships. The mining law of Mexico is of the most liberal character. It places no taxes in the way of extending properties. It gives to aliens the same freedom in locating and acquiring claims as to natives. It grants full title to mineral wealth below the surface without weakening in any way title to surface rights, provided always that the concessionaire complies with the law which requires the payment to the government of a fixed annual charge of five Mexican dollars per hectare, whether the operator develops the ground or not; whether it is mineral bearing or not, and whether it contains base or noble metals. Mining commissioners with well defined territorial authority are distributed throughout the country wherever mining is carried on. When cases of litigation arise between owners of adjacent properties the law is applied in an endeavor to reconcile the litigants by arranging agreements. The department of mines decides these cases when the parties at interest cannot agree, but maintains liberty of appeal in case of unwillingness to accept the decision of the lower court. The Department of Mines is under the control of the Minister of Agriculture. The mining law is uniform for the entire republic.

Although the Mexican government has been able to firmly establish its credit abroad and to demonstrate the efficiency of its judicial procedure at home it has found it necessary now for some years to permit stock companies organized abroad, and in accordance with the laws of other states, to carry on their administrative and financial affairs in accordance with those laws.

The most rudimentary feeling of nationality demands that this condition of things should cease and the Mexican government is actually studying the formulation of a law denying to alien corporations the right to denounce claims in Mexico; that is, it requires of such corporations that they organize under the laws of the republic. Every Mexican supports this law—and likewise every well-disposed foreigner, since in no respect does it affect the free action of capital nor the free development of enterprises. As for the natives they see in the proposed law a closer relation between foreign and national capital. They see the coming of mining companies, organized as provided in the law, in which small amounts of Mexican capital can find a more secure investment. The government can arrange for improving the conditions under which small investors place their funds and can thus encourage thrift. It may also perhaps establish banks for mines and an authorized mining stock exchange.

The great mines and metallurgical works distributed throughout the country are provided with the most modern equipment, and many of these are models in administration. The large smelters are at Cananea, Chihuahua, Torreon, Sta. Rosalia, Velardeña and Monterey where there are several (including an iron and steel plant of large capacity), Concepecion del Oro, Saltillo, Matehuala, San Luis Potosi, Aguas Calientes and Oaxaca. The large mills for concentrating and cyaniding are in El Oro, Guanajuato and Pachuca. Many smaller ones are distributed throughout the states of Chihuahua and Sonora, while numerous ones are either building or increasing their capacity in the states of Sinaloa, Durango, Tepic, Jalisco and Oaxaca. The first three mentioned, Guanajuato, El Oro and Pachuca are the largest, and together can treat 5,000 tons per day. In Sonora, Sinaloa and Tepic are several important works based on lixiviation.

The writer hopes that the preceding pages will give some idea of the actual mining conditions in Mexico. The business situation followed its normal course up to the end of the fiscal year 1906–07, but the financial crisis which developed in the middle of last year and affected all parts of the world caused many failures and aroused serious apprehensions. At the sud-

den drop in the prices of silver, copper and zinc many works shut down or restricted production. Other large works continued operations but without much profit. The situation is not altogether restored to the normal, but confidence is increasing, as the rate of interest on call loans falls off. Silver has made a small but firm advance; the strong consumption of copper shows few relations with existing conditions nor with diminishing production. It is to be expected that it will soon improve in price. The same conclusion is reached by a study of the great fluctuations in price which this metal has experienced in the last fifteen years.

ORE-DEPOSITS OF THE VELARDEÑA DISTRICT, MEXICO.

J. E. Spurr and G. H. Garrey.

LOCALITY.

The Velardeña district, Durango, Mexico, lies near the main line of the Mexican International Railroad, between Torreon and Durango.

GENERAL DESCRIPTION.

In this locality lies the Cuencamé River, dry most of the time. The valley of the Cuencamé where it cuts through the mining district, is from two to four kilometers wide. As a consequence of the aridity of the climate, the detritus stripped from the ranges has choked the valley and formed a smooth detrital floor from which the ranges rise sharply, the general appearance being similar to that of ranges in other arid regions, such as Arizona and Nevada, where it has given rise to the great fallacy of "Basin Range structure."

The Cuencamé valley has a northwesterly trend. On the southwest side the mountains are called the Santa Maria range; on the northeast, the San Lorenzo range. The ore-deposits lie in both ranges, and have been carefully studied and mapped. In the course of the examination the deposits of the whole area of upwards of 100 square kilometers have been studied.

GENERAL GEOLOGIC HISTORY.

1. The oldest formation, occupying the greater part of both ranges, is a blue, heavy-bedded limestone. Imperfect fossils collected by us are regarded by Mr. T. W. Stanton as Lower Cretaceous, though some resemble Jurassic types. This limestone series is very thick, but has not been measured.

2. Elevation of the limestone beds to form a land surface ensued, with very little folding: the uplift was followed by slight erosion, previous to

3. Explosive eruptions, and ejections of andesitic tuffs from volcanic centers, followed by copious flows and intrusions of andesite. The andesites are now found almost exclusively in the valley between the two ranges.

4. Folding of limestone and overlying andesitic rocks followed.

5. Next came explosive eruptions, and ejections of alaskitic tuffs from volcanic centers, followed by scanty flows of alaskite and trachytic alaskite. The dikes and volcanic necks belonging to this period are conspicuous in the Santa Maria range, but do not occur in the San Lorenzo range; while the surface products (breccias, tuffs and flows) occur in the San Lorenzo range, especially on its margin facing the Cuencamé valley, but were not noted in the Santa Maria range. At about the same time, there were extensive intrusions of dioritic rocks in the San Lorenzo range.

DESCRIPTION OF FORMATIONS AND EVENTS.

LIMESTONE.

The limestone which forms the larger portion of both ranges is the earliest of the formations exposed. In that portion of the Santa Maria range examined the limestone and overlying andesites have been uplifted in a great fold involving the whole front of the range. At the base of the mountains the rocks dip northeast at high angles, while the average inclination decreases toward the southwest and at the top of the range the strata are nearly flat.

In the San Lorenzo range the general structure of the folded limestone has not been worked out.

The thickness of this limestone series must amount to several thousand feet.

LOS MUERTOS FORMATION.

In a single, though fairly extensive area on the margin of the San Lorenzo range fronting the valley, is exposed a somewhat

problematical formation of dense texture and dark bluish-green color, which, however, is regarded as probably a series of metamorphosed Cretaceous shales. In other portions of northern Mexico such large shale bodies, conformable with similar thick limestone formations, are common. The formation here described has been metamorphosed into a hornstone. It is thin-bedded and lies conformably on the limestone below (which develops thin-bedded and shaly layers as this formation is approached) and is overlain unconformably by a limestone breccia which represents the bottom of the volcanic series of the alaskitic period.

This Los Muertos formation has been folded with the limestone so as to dip at steep angles.

The thickness of this formation must be upwards of a thousand feet.

ANDESITE.

Andesites overlie the limestones, with almost complete conformity, on the margin of the Santa Maria range bordering the Cuencamé valley. The first eruptions plainly broke up through the limestone explosively, and limestone fragments rained down on the surrounding country, mingled with andesitic ash. The basal bed of andesitic material, containing numerous angular fragments of limestone, records this phase. Subsequently, cleaner ash, and angular andesitic fragments were ejected, followed by eruptions of solid andesite.

The andesite also occurs in places in the Cuencamé valley, especially in hills lying in the extreme eastern part of the general area studied; but was not noted (except for a few small dikes) in the San Lorenzo range.

The rock is a hornblende-mica andesite. These eruptions are undoubtedly Tertiary in age, probably middle Tertiary, and from what is known of similar rocks elsewhere, may be provisionally regarded as Miocene.

CHIEF PERIOD OF FOLDING.

Subsequent to its formation, the Cretaceous series was uplifted and eroded, as is shown by the erosion interval evidenced between

the limestones and the andesites of the Santa Maria range; but there is not evidenced any more than very slight folding accompanying this uplift nor accompanying the andesite eruptions. Subsequent to the andesitic eruption, however, there was sharp folding, most of which took place before the alaskitic eruptions, as is shown by the unconformable overlie of the superficial deposits of the alaskitic period on the earlier formations.

ALASKITIC ROCKS.

The (intrusive) alaskitic rocks of the Santa Maria range are divisible into two types which are distinct in point of age—alaskite and trachytic alaskite, of which the former is the older, as is shown where the two come in contact. Both rocks are of alaskitic character, consisting essentially of quartz and mainly alkali feldspars, with biotite so rare as to be practically wanting, and no other ferromagnesian mineral. The difference between the two types is that the alaskite contains frequent and conspicuous quartz, while in the trachytic phases the amount of quartz (especially visible quartz) becomes greatly, though irregularly diminished.

Similar differences were recognized in the rather scanty surface flows of this period in the San Lorenzo range, and the thin but extensive flow which forms the last member in the volcanic series is of the trachytic facies. Nevertheless, there are many phases whose definite assignment to one or the other of the described divisions is difficult. The tuffs are hardly separable, but it was noted that the composition was apparently more typically alaskitic in the lower part, and more suggestive of the trachytic facies in the upper.

These rocks were found in the Santa Maria range only as dikes and volcanic necks. In many instances it is evident that necks of the alaskitic facies were subsequently reopened to admit the passage of the more trachytic facies, by which they were subsequently cemented. But in the San Lorenzo range we have phenomena showing interesting details of history.

Like the beginning of the andesite eruptions the alaskite eruptions were initiated by explosions, blowing out vents in the limestone; and these explosions were very severe, so that the shattered limestone fragments, falling, formed an important formation without admixture of igneous detritus. The thickness of this formation, where exposed, is about 200 feet. It is overlain by alaskitic tuffs and ash beds and the transition is marked by beds containing a mixture of limestone and igneous debris. Locally also, tuff beds, and even alaskite sheets occur within the limestone breccia formation.

The tuffs have an observed thickness of several hundred feet.

Overlying the tuffs is a sheet of trachytic alaskite. This sheet where studied is some 100 feet or less thick, but is found at intervals over a considerable part of the San Lorenzo range. Mainly it is confined to the foothills, but on the western part of the range it arches up over the summit. In one locality there is a little alaskitic tuff above the flow.

INTRUSION OF DIORITIC ROCKS.

In the San Lorenzo range there are enormous intrusions of dioritic rocks, such as were not found in the Santa Maria range. These intrusions appear irregular at first, but on closer study are seen to have taken place along two well-defined axial directions, the one due northeast, the other northwest.

DETAILED DESCRIPTION OF DIORITIC ROCKS.

The intruded dioritic rocks have phases which differ markedly from one another, and certain of the intruded masses as a whole differ very decidedly from certain others.

The largest mass mapped has a very dark blue color and a dense texture, and was provisionally called diabase in the field (1). About a mile from this lies a parallel series of intrusions, not so important, quantitatively, though still large. The rock of this is characteristically rather light colored and of a rather fine granular texture; and was provisionally called diorite in the

field (2). Not far from the last-named intrusion is a much smaller relatively siliceous intrusive mass, which was called monzonite (3). There are, however, numerous transitional types which have made it plain that we have here to do with three distinct phases of a single intrusive magma. There are smaller intrusions of these typical phases, but to keep in mind the chief intrusions enumerated above they will be named as follows: (1) The Terneras intrusion, (2) the Guardarraya intrusion, (3) the Copper Queen intrusion.

1. *The Basic Phase* (*Terneras Intrusion*).—This is a fine-grained dark-colored rock, with aplitic phases and phases containing mica. Some parts also grow relatively feldspathic and so more light-colored.

In different specimens studied microscopically, the structure varies from aplitic to granular. A typical specimen shows principally idiomorphic feldspar, with pale green augite, associated with magnetite, in a ground mass of fine granular feldspar and augite, with abundant small needles of apatite. There is, however, no uniformity. Another specimen differs from the last described in having abundant quartz and titanite, evidently among the last-crystallized minerals. Another specimen shows in addition to feldspar, augite, titanite, apatite and quartz, also pale green hornblende. In this case the earlier feldspars correspond to andesine-oligoclase: the later ones are probably more siliceous and probably include orthoclase. Other specimens having aplitic structure, contain, besides feldspar (including probably both calcic and alkalic species), quartz, augite, magnetite, apatite, and fresh abundant biotite; and in some cases there are pseudomorphs of granular augite and magnetite after probable hornblende. Since these specimens are all typical, it will be seen (though no analysis has been made) that the rock really belongs to the quartz-diorite or even in part the quartz-monzonite group, notwithstanding its frequent ophitic structure, and the high proportion of ferromagnesian minerals which give it its dark color.

Aplitic phases are marked by diminution of the ferromag-

nesian minerals, which may almost disappear. These aplitic phases are younger than the usual dark-colored rock, which they cut.

2. *The Intermediate Phase* (*Guardarraya Intrusion*).—The bulk of this rock as exposed (for example, in the Guardarraya intrusion) differs markedly from the bulk of the Terneras intrusion, in its light color and granular appearance. A typical specimen examined microscopically shows ophitic structure. This rock contains probably calcic feldspars, biotite, augite, quartz, magnetite, and sphene. The quartz, augite, and magnetite are later than the feldspar.

Another specimen from the same series of intrusions is very light colored, with very little ferromagnesian minerals. It has a porphyritic structure, and contains large phenocrysts of probably calcic feldspars, green hornblende and some biotite.

A specimen of rock classified on the whole with that of the Guardarraya intrusion but belonging to a distinct intrusion (the Pagina intrusion) shows a porphyritic structure, with phenocrysts of feldspar and augite in a ground mass of quartz, biotite, and augite. Pseudomorphs of augite, magnetite, biotite, and quartz, are after probable hornblende. This phenomenon of the occurrence of pseudomorphs after original hornblende is continually encountered.

Taken on the average this phase is distinguished by its light color and the relative scarcity of ferromagnesian minerals, by the frequency and probable predominance of hornblende over augite, and by considerable biotite. The rock is mineralogically and chemically closely related to that of the Terneras intrusion and is a quartz-diorite or quartz-monzonite.

3. *The Siliceous Phase* (*Copper Queen Intrusion*).—The intrusive rock near the Copper Queen mine is usually coarsely porphyritic, with many phenocrysts and very little ground mass. The phenocrysts include chiefly rather bluish feldspars, a considerable but variable amount of biotite, and occasional quartz. There are many varieties of different appearance, dependent upon the proportions of the different minerals. Some phases may be

called granitic, and biotite-poor varieties become aplitic. Mr. S. H. Ball observed in a specimen from this intrusion, pseudomorphs of biotite after probable hornblende. The rock appears to be a rather siliceous quartz-monzonite and its occurrence as noted is limited to the single small intrusion near the Copper Queen mine.

RELATIONS OF DIFFERENT PHASES.

The rocks of these three main intrusions (with one or the other of which the remaining intrusions may be more or less exactly correlated) represent a gradual change from an augite diorite with diabasic aspect to granitic phases. The Terneras intrusive, speaking broadly, is a dark dense diorite with predominant ferromagnesian minerals consisting principally of augite, with occasional biotite and rare hornblende; but the rock has a constant tendency to pass into forms which are classifiable as quartz-monzonite. The Guardarraya and Pagina intrusions consist essentially of rock of medium light color, with the ferromagnesian minerals present only in moderate quantity, and hornblende probably predominant over augite and biotite, both of which occur frequently. The Copper Queen intrusion is of a light colored rock of granitic appearance with a relatively small amount of ferromagnesian minerals, and biotite in excess of hornblende and augite, both of which, however, occur in its different phases. Yet in the Terneras and Copper Queen intrusions types which are also frequently encountered in the Guardarraya intrusion may be found; so that the proposition that all are variations of a single magma is upheld. In the Terneras rock-types, pseudomorphs of augite and magnetite after hornblende are repeatedly encountered; and in the Copper Queen specimens, as above stated, a pseudomorph, after hornblende of biotite was noted. This suggests that in the original magma hornblende was the first ferromagnesian mineral to crystallize, and hence that the magma was an intermediate one, representing more or less a mean between the resultant types.

The fact that the later aplitic phase, cutting the main rock of the Terneras intrusion (and differing from the main rock

in its greater proportion of siliceous minerals such as quartz and alkali feldspar, and less proportion of ferromagnesian minerals) corresponds exactly with a prominent phase of the Guardarraya intrusion, indicates that the Guardarraya rocks as a whole belong to a later differentiation period than the Terneras rocks; and this conclusion coincides with the results of the microscopic study of the rocks, which shows that the less siliceous minerals, such as calcic feldspars and augite (of which the feldspar was usually earlier) were first to crystallize, while orthoclase, quartz and titanite were later. This indicates an earlier crystallization of calcic minerals and a later crystallization of siliceous and alkaline minerals; and the individual rock types vary in proportion to the stages represented, and the relative quantity of the products of each. A further extension of this idea suggests that the Copper Queen intrusion on the whole represents a later stage than the other two.

According to this, from an intermediate dioritic magma, the products of the first consolidation formed a rock (ophitic augite diorite) rather more basic than the original magma, being composed chiefly of the first precipitated, more basic constituents; the products of later consolidation, mingled with some of those of the earlier consolidation, formed a series of quartz-diorites and quartz-monzonites, growing more siliceous and more scanty. This hypothesis is strengthened by the fact that the earlier more basic intrusions (of which the chief one is the Terneras intrusion) are quantitatively most important; that rocks of the type of the Guardarraya intrusion are much less abundant, and the siliceous type represented by the Copper Queen intrusion is only found in a single relatively small mass.

The composition above reasoned out for the undifferentiated magma which produced the more or less differentiated products shown in the dioritic intrusions corresponds to that of the andesite whose eruption preceded those under discussion. It seems a plausible hypothesis, therefore, that the andesite represented outbursts of this same magma, before differentiation began.

AGE OF DIORITIC INTRUSIONS.

The various dioritic intrusions, embracing the different types above described, appear to have taken place at nearly the same time.

In two different localities the more basic phase (in the Terneras intrusion and also the San Isidora intrusion) were noted as being intrusive into the alaskitic tuff series. At the former locality, also, the dioritic rock appears to be overlapped by the capping trachytic alaskite flow. Thus the age of the intrusion is definitely fixed as in general contemporaneous with the alaskitic intrusions and eruptions.

RELATION OF DIORITIC TO ALASKITIC INTRUSIONS.

The alaskitic intrusions, as now exposed in the Santa Maria range, represent a sub-magma of a decidedly more siliceous and alkaline composition than even the granitic phases of the Copper Queen intrusion, but one that might normally be considered as representing a further step in the differentiation of the same intermediate magma above postulated.

FOLDING DURING AND AFTER THE ALASKITIC ERUPTIONS.

As above stated, the main period of folding preceded the alaskitic eruptions. The unconformity between the underlying limestone and probable metamorphosed shale, and the overlying formations of alaskitic period, is very abrupt, the limestones being nearly vertical, while the volcanic formations are almost horizontal. Nevertheless, there was some tilting during the volcanic activity. The limestone breccia and the overlying tuff series, as they occur along the southwestern margin of the San Lorenzo range, are locally horizontal, but elsewhere they dip either into or away from the range, at usually slight angles, reaching locally 40°; and where the dip is noticeable there is an unconformity between the tuffs and the overlying trachytic alaskite flow, which is more nearly horizontal, and usually slopes gently away from the range. That this slope also is due to crustal flexing is shown by the fact that at the west end of the range

this flow, partially destroyed by erosion, arches up over the entire range. This shows that San Lorenzo range, as we see it, is chiefly an anticlinal range of deformation, this anticline having having been impressed upon a plain of erosion underlain by highly folded and base-levelled limestone and covered with the products of the alaskitic vulcanism.

METAMORPHISM.

All the intrusive igneous rocks noted are connected with metamorphism in such a way as to prove the intimate relation between intrusion and metamorphism.

METAMORPHISM OF DIORITIC INTRUSIVES.

Metamorphism of Rocks of the Basic Phase.—The basic phase of dioritic intrusions, represented chiefly by the Terneras intrusion, is attended by much metamorphism. This process has only acted in the immediate vicinity of the igneous rock, hence belongs to the class of contact metamorphism. Thorough study shows that not only is the limestone into which the igneous rock has intruded metamorphosed, but that the igneous rock has itself been profoundly altered in the same way, furnishing products often difficultly or not at all distinguishable from those resulting from the metamorphism of the limestone. Indeed, the amount of metamorphic rock which has resulted from alteration of the igneous rock is plainly several times as great as that resulting from the alteration of the limestone. The alteration of the limestone is ordinarily confined to a relatively narrow belt on the margin of the intrusion, which probably rarely exceeds 100 meters in width, and is usually much less, while that of the diorite penetrates irregularly the whole mass of the intrusion. This and other circumstances show that the alteration was accomplished by waters whose advent occurred subsequent to the entire consolidation of the intrusive rock. Yet the fact that they were confined to this rock and its borders shows that they rose (through fractures made subsequent to consolidation, as the detailed study indicates) along the intrusive neck. It is therefore probable that the intrusive rock and the distinctly sub-

sequent metamorphosing solutions were derived from a common center.

The alteration of the igneous rock of the Terneras intrusion has been well observed at the surface, but to especial advantage in the immense underground workings of the Terneras mine, where there may be found every stage of the metamorphism, from the condition where the metamorphic rock forms narrow belts bordering occasional fractures in the fresh rock, through stages where the change has penetrated along numerous reticulated fractures, so that only residual patches of the dark igneous rock remain, to the complete transformation of the whole mass of original rock to an aggregate of metamorphic minerals.

A specimen from the eighth level of the mine illustrates the beginnings of metamorphism. The rock is an augite diorite, of coarse granular-ophitic structure. The feldspars are large, and fairly fresh, but differ from the normal occurrence in containing small green augite crystals, as if the augite were secondary. In the interspaces between the feldspars is abundant grass-green fresh augite, with abundant magnetite, titanite and apatite.

A specimen from the Terneras tunnel is an augite diorite of even, granular structure. The abundant fresh feldspars give the extinction angles for andesine-oligoclase. There is fresh abundant grass-green augite with associated magnetite, and frequent apatite. All this is quite normal, but the hand specimen of this rock shows a pegmatitic segregation showing siliceousness increasing from the margin toward the center, and terminating in a central open vug. The chief mineral of this pegmatitic growth is orthoclase, with both light and dark green augite, quartz and pyrite, all contemporaneous. The vug is lined with free crystals of orthoclase, upon which are sparse later crystals of light-green augite.

A specimen from La Chona tunnel shows as principal minerals feldspar and grass-green augite. The augite is fresh; the feldspar fresh, but much strained. The augite is clouded by magnetite along its cleavage planes. There is abundant magnetite, titanite, and apatite. Fresh brown biotite occurs in certain parts of the slide, especially as rims around the larger mag-

netite grains. There are also abundant small pseudomorphs after biotite, consisting of magnetite (with some contemporary pyrite) following the rays of the pressure figure, and extending therefrom to a varying extent up to complete replacement. The portion of the biotite that has not been replaced by the magnetite (and pyrite) has been altered to green chlorite.

Apparently, therefore, the sequence is approximately this: (1) Feldspar, (2) augite and biotite, (3) magnetite, pyrite and chlorite, (4) biotite.

The hand specimen indicates that this rock has been acted on by metamorphic processes.

A small kernel (a few inches in diameter) of dark dioritic rock from the Terneras mine, altered on the margins so as to be unrecognizable, penetrated by veinlets of metamorphosed rock, and impregnated with pyrite plainly dependent on the metamorphism, shows under the microscope chiefly augite and probable orthoclase—the former fresh except for alteration along cracks to serpentine (?), the latter largely altered—to kaolin (?). The rock contains occasional pyrite (no magnetite), frequent apatite, and an unusual quantity of titanite.

A specimen from the surface, in the central part of the Terneras intrusion, shows in the hand-specimen a dense dark rock, cut by a light-colored aplitic streak; while both are cut by a still lighter-colored (pale pink) veinlet. The microscope shows that the dark rock consists of about nine-tenths granular grass-green augite, and one-tenth striated, presumably calcic, feldspars; both minerals being fresh. The light-colored aplitic veinlet cutting the dark rock consists of four-fifth probable orthoclase, with a little oligoclase, which has been altered to orthoclase on its margin. Of the remainder, one-tenth is crystalline epidote and one-tenth colorless pyroxene. There is also relatively abundant titanite and some calcite and quartz. The latest veinlet noted in the hand specimen is not shown in the thin section.

A suite of specimens were taken from a single spot in the eighth level of the Terneras mine, to show stages of metamorphism. The first of the series shows a residual kernel of dark dioritic rock enclosed in a metamorphic rock of which the igneous struc-

ture is still visible. A thin section of the dark kernel shows porphyritic-ophitic-granular structure; and the texture is relatively fine, save for occasional large feldspar phenocrysts. The rock contains andesine-oligoclase, largely altered to fine muscovite, brown biotite, and occasionally to augite. It is also altered along cracks to clear orthoclase, which contains a little biotite and green hornblende; and orthoclase occurs as rims around some of the calcic feldspar crystals. Similar probable fresh orthoclase occurs in the ground-mass, with abundant fresh pale-green augite, biotite, magnetite, and apatite. The order of crystallization in the rock seems to have been as follows:

1. Large crystals of andesine-oligoclase.

2. (*a*) Magnetite, (*b*) biotite, (*c*) augite, (*d*) orthoclase and apatite, in about the order named. Extensive magmatic alteration of andesine-oligoclase to orthoclase, and to a less degree to muscovite, biotite, and augite, is shown.

The second specimen in this series shows an advanced stage of metamorphism, but the original igneous structure is still visible. The thin section shows that the large feldspar phenocrysts of the first specimen, together with rims of subsequent orthoclase, and also probably biotite, have been completely altered to white garnet; while the rest of the rock is colorless pyroxene, of later origin, filling interstices and veins in the garnet aggregate.

The third specimen in this series is like the second, but more altered. Besides the white garnet, impure from probably residual material, a less quantity of clear crystalline garnet appears. The fourth specimen is like the third, but represents a still more complete recrystallization. The garnet is better crystallized, and the pyroxene is clearer. The rock is cut by veinlets of calcite. In the hand specimen of the third example the original igneous structure is barely perceptible; in the fourth it is quite indistinguishable, though the general appearance of this rock-type, its origin being once thus established, is sufficiently characteristic (from its light yellow-green color and fine crystalline texture) to allow its subsequent recognition elsewhere in this mass as the result of metamorphism of diorite, and not of limestone.

Another specimen of indubitable metamorphosed diorite from near the center of the intrusion consists of yellow-green garnet and colorless pyroxene, the crystals being embedded in dense aggregates containing probable sericite and zeolites (?).

Metamorphism of Rocks of the Intermediate Phase.—The intermediate intrusions, including the Guardarraya and the Pagina intrusions, are usually attended by a relatively narrow border of metamorphic rock, averaging perhaps twenty meters, sometimes greater and sometimes entirely wanting. This border apparently is chiefly the result of the metamorphism of the intruded limestone; and metamorphism of the igneous rock is very slight as compared with the extensive and intense alteration of the Terneras intrusion. Nevertheless, interesting phenomena of the alteration of the rock of the intermediate intrusions were noted.

At Los Ojos, near the contact, the diorite is cut by aplitic dikelets and seams, containing feldspar and pyroxene; they also carry brown or green garnet. Sparse or abundant veinlets containing much garnet cut through those containing less. In some cases a veinlet has feldspar on the walls and garnet in the center, the succession plainly representing the order of precipitation from a single source. Other veinlets show garnet on the sides and calcite in the center, the two intercrystallized and contemporaneous at the transition. Seams of solid garnet in the diorites reach several feet in thickness.

A small hand specimen from this locality shows (*a*) dark-green dioritic rock, cut by (*c*) an aplitic dikelet or vein, which has (*b*) a narrow pale green inconspicuous selvage. In thin section (*a*) has a porphyritic ophitic structure and consists mainly of idiomorphic to hypidomorphic feldspar, probably both calcic and alkalic (orthoclase); the rest is pale green allotriomorphic (and so subsequent) pyroxene. The selvage of the vein (*b*) is a band of finely granular feldspar, as if formed from the trituration of the feldspar of (*a*). In this is the same pyroxene (unbroken) as in (*a*) but more abundant; and a single cluster of crystals may extend from (*a*) to (*b*). This shows that the augite of (*a*) and (*b*) was deposited subsequent to the fissuring

and granulation of the feldspar. Titanite, unbroken (and so later than the fissuring), is present in both (*a*) and (*b*) but is more abundant in the latter. The main vein (*c*) consists of contemporaneous orthoclase, garnet, and some pyroxene. A small veinlet of garnet leaves (*c*) and cuts distinctly through (*a*) and (*b*). This garnet veinlet is in turn cut by a fissure veinlet whose sides are fringed with tiny orthoclase crystals, while the center is filled with colorless to yellow-green pyroxene (of a different shade from the pale grass-green pyroxene of *a, b* and *c,* which pyroxene it locally cuts). Another section of the same specimen shows *a* and *b* of the same character, but (*c*) consisting of pale green garnet, beautiful crystalline green chlorite, and quartz, all contemporaneous, with some striated feldspar, abundant orthoclase,[1] actinolitic amphibole, epidote and a little apatite. Grass-green pyroxene here forms a slight band between (*b*) and (*c*). The order of crystallization appears to have been as follows: (1) Soda lime and orthoclase feldspars. (2) Fissuring, and granulation along walls of fissure. (3) Pale grass green augite (with contemporaneous titanite) introduced in the uncrushed rock and in greater amount in the crushed selvage, and forming a slight layer on the fissure walls. (4) Deposition, in the fissure, of some augite, with abundant orthoclase, garnet, and some quartz, striated feldspar, actinolitic amphibole, epidote, apatite, and probably colorless pyroxene.

A specimen of altered dioritic rock at the contact of this same intrusion, near the Guardarraya mine (and very close to unmetamorphosed limestone) shows numerous probably originally feldspar phenocrysts, now entirely altered to dense carbonates, dense garnet and colorless pyroxene. The altered groundmass consists mainly of garnet, with finely crystalline colorless pyroxene, pyrite, dense carbonates, and quartz. Veinlets, cutting the rock, contain garnet, calcite, and some colorless pyroxene; near such veinlets, the rock has been recrystallized to garnet, colorless pyroxene, and quartz or orthoclase.

A specimen from the same general intrusion (from near the contact at the Tiptop mine) contains principally feldspar and

[1] Determination of orthoclase checked by F. E. Wright.

hornblende, with some biotite, apatite, and pyrite. The hornblende is entirely or partly altered to colorless pyroxene; the biotite is partly altered to quartz and probable colorless pyroxene; the pyrite is largely altered to magnetite.

Metamorphism of Rocks of the Siliceous Phase.—The body of quartz-monzonite near the Copper Queen mine is bordered along certain stretches by metamorphic rock; elsewhere there is no contact-metamorphism. Where metamorphism is present, it has attacked both the limestone and the igneous rock; and frequently the products of the alteration of the two rocks are not distinguishable one from the other.

In the process of alteration, the feldspars are decomposed and partially or entirely obliterated; the biotite withstands the attack fairly well, and is often fairly fresh in highly altered rock, but also finally succumbs. No microscopic examination was made, but garnet, diopside, calcite, quartz and sulphides were noted as metamorphic minerals. Seams of metamorphic silicates, and also seams of sulphides, penetrate the igneous rock for some distance away from the contact.

Résumé of Metamorphism of Dioritic Intrusions.—The above data indicate an unbroken sequence of crystallization, beginning with the earliest minerals formed in the igneous magma, passing to the formation of the later rock minerals (at which period the earlier ones were somewhat altered) and thence with no abrupt break, to minerals commonly recognized as the products of "metamorphism" (from the fact that they replace earlier minerals), and so on to the commoner vein minerals, such as quartz and calcite. It also shows that as the process of crystallization went on, the new (residual) materials were more prone to attack, and to become quantitatively effective in replacing and altering, the earlier minerals, indicating that the magma became more mobile and penetrant, which probably means among other things that the magma became much more aqueous. Moreover, the process of events seems to have been similar at the various intrusions.

The earliest minerals deposited from the dioritic magma appear to have been (A) calcic feldspar (chiefly andesine-oligoclase) and some hornblende. This was succeeded by (B) magnetite,

biotite, and grass-green pyroxene, which partly replaced in unusual cases the feldspar and commonly entirely replaced the hornblende, and crystallized in unoccupied spaces in the rock fabric. This was succeeded (though with no sharp break, so that the crystallizations overlap) by (C) orthoclase, apatite, titanite, chlorite, quartz, pale-green pyroxene, and pyrite. This was succeeded by (D) garnet and pyroxene (usually colorless); and this by (E) quartz and calcite.

In the above rough sketch of the sequence the A stage, the A + B stage, or the A + B + C stage form products which are usually grouped as "ordinary" igneous rocks; the C stage, or the C + D stage, or the C + D + E stage form products which are recognized either as "igneous rocks" or as "pegmatitic and aplitic after products": while the deposits of the D stage, or the D + E stage, or the E stage, where crystallized free are commonly regarded as "veins." While the minerals of each stage have been found at Velardeña to form frequently by replacement of minerals of an earlier stage, which have become soluble in the changed mother-liquor, yet the D stage is preëminently that which to the greatest degree has replaced already existing minerals and is thus par excellence the stage of "metamorphism," though the C, the C + D, the C + D + E, the D + E and the E stage are conspicuous in the same way. Such "metamorphic" minerals have been frequently regarded as dependent upon the synthesis of the limestone with metamorphosing solutions; but the fact that the predominant minerals—garnet and pyroxene—in this region are produced at the expense of the limestone and basic, intermediate and siliceous igneous intrusives alike, shows that the formation of these minerals is in large part independent of the intruded or replaced rocks.

METAMORPHISM OF ALASKITIC ROCKS.

Metamorphism of Alaskites.—The alaskite intrusions in this Santa Maria range are bordered by a definite zone of metamorphosed limestone, but there is a relatively small amount of

metamorphism in the igneous rock. Metamorphosed alaskite does occur; but has not been carefully studied. Secondary fluorite was noted in a specimen of otherwise fresh alaskite from one of the main intrusions.

On the San Lorenzo range, the alaskite flows and tuffs have been locally metamorphosed by the solutions which were so intimately connected with the dioritic intrusions. These solutions have penetrated most thoroughly along certain porous formations and porous layers, showing their aqueous nature. A specimen of alaskite from the Dulce Nombre district, near the contact of the basic phase of the dioritic rock, shows the usual quartz and orthoclase phenocrysts, in a feldspathic and quartzose ground mass. In the ground mass are developed, as metamorphic minerals, abundant colorless pyroxene and grass-green epidote.

The tuffs are often considerably metamorphosed. A specimen of little-sorted alaskite tuff from the Terneras road in the foothills shows fragments (remains of phenocrysts) of quartz and orthoclase, pseudomorphs of epidote after original ferromagnesian minerals, and apatite. The finer material is mainly quartz, with calcite, epidote and a little colorless garnet. Another specimen of metamorphosed tuff from this same formation, from the breast of Caldas tunnel, has been transformed to sericitic material, penetrated, especially along parallel bands, with colorless pyroxene or garnet. Still another specimen from a tuff layer in the volcanic limestone breccia formation at San Isidora shows rounded fragments of quartz and feldspar, with secondary colorless pyroxene, and apple-green pyroxene.

Metamorphism of Trachytic Alaskite.—The trachytic alaskite is locally altered in the same way as the more typical alaskite. A specimen from the main trachytic intrusion near the contact shows complete metamorphism to fine-grained garnet, with a little calcite and pyroxene.

METAMORPHISM OF LIMESTONE.

Around all the intrusive rocks described the limestones are metamorphosed. Certain portions of the contact are unattended

by metamorphosed limestone; elsewhere, the altered belt is thick. Occasionally metamorphic bands extend a long distance away from the contact, the solutions evidently having penetrated along some bedding or fracture-plane.

Metamorphism of Limestone around Dioritic Intrusions.

Metamorphism of Limestone around Intrusions of the Basic Phase.—It was noted that around the Terneras intrusion, the chief alteration product of the limestone close to the contact was garnet, with vesuvianite along cracks and fissures. Nearer the limestone, colorless pyroxene (?) appeared to become much more characteristic. Specimens from the metamorphic belt near the contact contain pale-green garnet, calcite, hematite or magnetite, chlorite aggregates, epidote, and quartz.

A specimen from the eighth level of the Terneras mine, of a white metamorphic rock (probably metamorphic limestone) has been determined by Dr. F. E. Wright, who finds it to be a hitherto unknown mineral, a hydrous calcium silicate ($Ca_2SiO_4H_2O$) which he has called hillebrandite.[1] Dr. Wright noted wollastonite in seams in the hillebrandite.

In the field it was noted that a light greenish rock, weathering a peculiar bluish tinge, formed the outer belt of metamorphism around at least a considerable part of the Terneras intrusion, adjoining the more or less recrystallized blue limestone. Generally a zone of garnet rock (probably metamorphosed limestone) intervenes between the outer zone and the metamorphosed or fresh igneous rock; but sometimes the outer bluish-weathering rim and the igneous rock come together, with no intervening garnet band. This is taken to signify that the bluish-weathering rock is a later formation than the garnet rock. A specimen of this bluish-weathering rock was found by Dr. Wright to consist essentially of a hitherto unknown mineral, a calcium silicate-carbonate, which he has called spurrite.[1] This rock occupies a definite belt 25 to 50 meters wide. Another specimen, from the same locality as the last, is of a dark crystalline rock. It shows

[1] See Dr. Wright's descriptions *On Three Contact Minerals from Velardeña, Durango, Mexico,* Am. Jour. Sci., 4th series, **24**: 545–554, 1908.

colorless pyroxene, a little yellowish garnet, a little magnetite, some rutile, and considerable gehlenite[1] ($Ca_3(AlO_2)Si_2O_8$). This mineral, which was determined by Dr. Wright, is here for the first time recognized in America. The order of crystallization seems to have been: (1) Gehlenite, (2) magnetite, (3) colorless pyroxene (?), (4) rutile. In other specimens Dr. Wright found gehlenite and spurrite associated. Another specimen from the same belt, at a point about 175 meters from the locality just described, and apparently about on the border between the undoubted metamorphosed limestone and the metamorphosed diorite, consists almost entirely of gehlenite with some subsequent magnetite.

Metamorphism of Limestone Around Intrusions of the Intermediate Phase.—A single specimen from the metamorphosed limestone belt at Los Ojos, on the border of the Guardarraya intrusion, consists of garnet and colorless pyroxene, with probably subsequent calcite and chalcedonic quartz. A specimen from the same contact at another point, contains garnet, calcite, hematite or magnetite, chlorite, epidote and quartz. Another specimen from the contact of the Las Animas intrusion contains garnet, calcite, magnetite, quartz, apatite and orthoclase (adularia).[2] Adularia is intercrystallized with calcite and quartz.

Metamorphism of Limestone Around Intrusions of the Siliceous Phase.—A specimen of ore from the fifth level, Copper Queen mine, contains mainly calcite, with yellowish green garnet and magnetite, and cupriferous pyrite. The calcite is largely altered to serpentine (?). Another specimen from the same level shows also garnet, and calcite largely altered to serpentine. Of later date, and forming veinlets in the older minerals, are cupriferous pyrite and magnetite (or hematite in part). There is a certain connection between the metallic minerals and the serpentine, but on the whole it appears the serpentine was probably somewhat later. Order of minerals replacing limestone:

[1] *On Three Contact Minerals from Velardeña, Durango, Mexico,* Am. Jour. Sci., 4th series, **24**: 545–554, 1908.

[2] Determination of adularia checked by Dr. F. E. Wright.

(1) Garnet, (2) magnetite, hematite, cupriferous pyrite, (3) serpentine and quartz.

Metamorphism of Limestone Around Alaskitic Intrusions.

The intrusive alaskitic rocks of the Santa Maria range are surrounded by a border of limestone which has been largely altered to silicate minerals, such as garnet and pyroxene. Crystalline calcite and quartz also characterize this zone, as well as sulphides, chiefly iron (pyrite), frequently cupriferous, with not infrequent zinc blende, and occasional galena. Certain portions of the contact show a broad zone of metamorphism, while other portions of the same contact show practically none at all.

Metamorphism of Limestone Around Alaskite Intrusions.—A number of specimens of altered limestone around alaskite intrusions were studied. One specimen shows the following history: (1) Regeneration of original calcite, (2) replacement of most of calcite by colorless pyroxene (diopside), (3) partial replacement of pyroxene by vesuvianite, (4) quartz and calcite in cracks in diopside-vesuvianite rock.

Another shows the following: (1) Regeneration of calcite, (2) partial alteration of calcite to garnet, (3) partial alteration of calcite to pale green amphibole, (4) pyrite and specularite, (5) blende. A third shows: (1) Original fine calcite, (2) garnet, (3) serpentine.

Metamorphism Around Trachytic Alaskite Intrusions.—A specimen from the border of a large trachytic alaskite intrusion shows limestone principally altered to fine garnet. Another from a different locality shows mainly garnet; also pseudomorphs after some prismatic mineral, these pseudomorphs consisting of calcite, actinolite, chalcedonic quartz, red hematite and specular iron. Calcite and some quartz, with contemporaneous specular iron, occur in veinlets in the garnet. The order of crystallization is: (1) Garnet and pyroxene (?), (2) quartz, calcite, actinolite, and specular iron.

A specimen from the contact of a trachytic alaskite dike in the Santa Maria mine (fourth level) shows the following order of crystallization: (1) Garnet, calcite and quartz, (2) pyrite and zinc blende.

Metamorphism of Limestone Breccia.

The volcanic limestone breccia whose formation was the result of the first volcanic explosions of the alaskitic period has been partially metamorphosed. A specimen of this shows the calcite altered mainly to fine fibrous colorless pyroxene, and abundant garnet.

METAMORPHISM OF LOS MUERTOS FORMATION.

The Los Muertos formation (p. 689) is apparently a metamorphosed shale, whose complete alteration has been due to the fissile character which permitted the ready passage of solutions. Specimens of this hornstone show fine calcite, epidote, abundant probable vesuvianite and probably some secondary quartz.

RESUMÉ OF METAMORPHISM.

In the Velardeña district intrusions of diverse composition (though belonging to a single igneous epoch) have been attended by metamorphism, which is characteristically confined to the immediate vicinity of the individual intrusions, and is most common at the contacts. In all cases studied the metamorphism was definitely subsequent to the intrusion. In many cases a greater amount of the limestone is more altered than of the intrusives; in others the results are about equal; and in important examples far more of the igneous rock than of the limestone has been completely metamorphosed. The difference may perhaps depend somewhat upon variations of heat and pressure, determining intensity of action. With a slight degree of intensity, it is natural that solutions which would act but lightly upon a mass of silicates like an igneous rock would change the limestone strikingly. Another factor is probably the nature of the igneous rock. As the metamorphosing solutions appear to have been siliceous, they would attack the most siliceous rocks least. Actually the alaskitic rocks are very little metamorphosed; while of the dioritic intrusions the most basic has been the most profoundly metamorphosed.

The data indicate in many cases indubitably and in all cases

as the most probable hypothesis, that the metamorphosing solutions rose up along the consolidated pipes of igneous rock, through cracks and fissures; but that in some cases these channels existed mainly along or near the contact.

By far the most prominent minerals of the metamorphic rocks are garnet and (usually colorless) pyroxene. The fact that these minerals have been developed at the expense of various dissimilar igneous rocks, from alaskite to basic augite diorite, and also from limestones, shales, and tuffs situated around these various intrusions, shows that the process of metamorphism was not primarily one of paramorphism (recrystallizing the rock elements under a different form), or of synthesis (by which materials brought in by solution combined with those of the rock to form new minerals), but of replacement; nevertheless, the two first named processes are undoubtedly important, and one or the other may frequently be predominant locally. Moreover, this similarity of products argues the essentially similar chemical character of the solutions which followed intrusions themselves widely different chemically.

There are interesting minor differences, dependent upon the rock attacked and also apparently upon the especial igneous rock with which the metamorphism is associated. The mineral spurrite is plainly characteristic of the effect of siliceous solutions upon limestone; moreover, the characteristic belt of this rock was noted only around the Terneras (basic dioritic) intrusion. The minerals hillebrandite and gehlenite have so far been noted only at the contact of this same intrusion. Specularite was very noticeable around the intermediate dioritic intrusions (Guardarraya and Pagina intrusions) as compared with the others. In the alaskitic rocks fluorite was frequently observed in and at the contact of the trachytic alaskite, but was rarely observed in the ordinary alaskite intrusions.

ORE-DEPOSITS.

ORE DEPOSITS CONNECTED WITH DIORITIC INTRUSIONS.

Ore Deposits Connected With the Basic Phase of Dioritic Intrusives.

Ore Deposits of Terneras Group.—In the Terneras intrusion of basic dioritic-monzonitic rock there are numerous nearly vertical relatively persistent parallel east-and-west veins. These characteristically run diagonally across the intrusion, from side to side. Their productive portion is essentially confined to the diorite and the metamorphic rock; the veins pass into limestone, but on doing so weaken and soon disappear. Yet they occur, at close-spaced intervals, in the whole of this irregular intrusion, the longest (northeast) axis of which, as mapped, is some 4 kilometers in length.

The relations of the solutions which deposited the veins to the igneous rock are then seen to be similar to those of the metamorphosing solutions to the same rock. The fact that the veins are practically confined to the intrusion, in which they lie along fracture and fissure-zones, shows that the vein-forming solutions rose up along the igneous neck, and were probably derived from the same source as the diorite.

The intense metamorphism connected with this Terneras intrusion shows absolutely no attendant mineralization (deposition of metallic minerals in concentrated form) at any point.

The veins cut the metamorphic rock of the Terneras intrusion, and so are later. Some of them (as the Caldas) cut the alaskitic tuffs, and in some cases (as the Tecolotes vein) they cut the trachytic alaskite which was the last of the formations of the alaskite period.

The vein channels, as a rule, were crushed fracture zones, where the vein has replaced the crushed material; locally, there is some fissure-filling. These fracture zones were accompanied by only slight differential movement, or faulting. The history of the veins, as will presently be pointed out, shows different stages, marked by totally different vein-materials; and the materials rep-

resenting the various stages have been successively deposited along channels successively formed by the rending apart of the old zone of weakness which had been cemented by the earlier deposition. In other words, the strain which formed the first vein-channels was afterward continually felt, continually reopening the break as it was repeatedly healed by vein formation; and the openings became successively wider and wider, till at the end open fissures of considerable width were formed. The period of movement followed the igneous intrusion, and probably was dependent upon adjustments of equilibrium resulting from the intrusion.

The intrusions probably took place in the middle or later Tertiary (Neocene period); there followed the fracturing which gave access to solutions from below and brought on the period of metamorphism; then followed a continuation of the fracturing, cutting the metamorphosed rock, giving access to solutions, and bringing on the period of vein-formation. The record of consecutive openings shows that the stages of vein-formation were each very brief, and the whole vein-period of disssimilar sucessive stages was very short as compared with the period of movement. The latest stage of the vein-deposition, as will be shown, was barren calcite, and this occurred at a period when heavy faults had developed. These faults are not very recent, since their great displacements are not represented directly in the topography. Their growth, therefore, did not occupy a very long geological period; yet the whole period of metalliferous vein-formation occupied only the early part of the period of movement.

The metamorphism attending this Terneras intrusion was distinctly later than the intrusion: yet it has been shown elsewhere that the period of metamorphism probably represents the later stages of the period of magmatic crystallization and that no real gap exists between this and the earlier stages. The veins cut the metamorphic rock, but it will presently be shown that they probably do not represent a distinct process and cause, but a continuation of the crystallization of the metamorphic period, with connecting links between. The different vein-stages cut one another sharply; but natural relations of succession are believed

to be represented, not distinct processes. One of the most striking features brought out is that a given period of vein-formation appears to have lasted only a short time, and is a definite point of geological history, comparing in exactness and clear definition with the intrusion of an igneous rock and not with processes which are of extensive duration.

In the Terneras vein the following distinct stages are seen at one point on the fourteenth level of the Terneras mine, within the same walls, each stage splitting the earlier, showing that re-openings of the vein-channel occurred between each cementation:

A. Finely crystallized cupriferous pyrite, with other less conspicuous sulphides in a granular quartz gangue.

B. Very coarse galena and blende. No gangue.

C. Fine "mixed carbonates"[1] and quartz, with sparse sulphides. Vein crustified.

D. Barren coarse calcite, often brown from inclusions of iron oxide.

Samples taken of these different stages assayed as follows:

	Au, Grams.	Ag, Grams.	Pb, Per Cent.	Zn, Per Cent.	Cu, Per Cent.
A	60	3,690	7.9	3.8	3
B	1	3,023	38.9	27.1	1
C	tr.	74	00.0	0.6	tr.
D	tr.	40	00.0	0.4	tr.

A thin section of each of the stages shows as follows:

A. Much cupriferous pyrite and yellow-green resin blende and a little galena (with possibly some tetrahedrite), all contemporaneous, in a gangue of contemporaneous quartz and rhombohedral carbonates (not calcite; probably mixed carbonates[1]). Both quartz and corbonates are packed with dark inclusions—perhaps sulphides. Another section shows cupriferous pyrite, galena and quartz. One pyrite crystal is surrounded by a later mineral which may be tetrahedrite.

B. Resin blende, coarse galena, and a very little cupriferous pyrite, all contemporaneous. The blende is traversed by numerous veinlets of later probable tetrahedrite.

[1] See page 715 for definition of this phrase.

C. Carbonates, curved wavy extinction.

D. Coarse crystalline calcite.

Following are notes from other localities on the vein:

A stage. At the west end of the eighth level Terneras, where the vein lies in crystalline limestone walls, the vein material contains silicates. A thin section shows zinc blende and an undetermined blue-black metallic material, in a gangue of crystalline quartz, carbonates, and a prismatic undetermined silicate. A little chalcedony is present.

C stage. The "mixed carbonates" of C have fine crystallization, pearly luster, and pinkish to grayish colors. Similar carbonates in the San Mateo vein show on test the presence of manganese, iron, lime, and probably magnesium. It appears possible that this is a definite mineral, not yet differentiated from other crystalline carbonate mixtures. Similar "mixed carbonates" of lime, magnesium, iron, and manganese have been found by the writer in the veins of Tonopoh, Nevada, and Georgetown, Colorado.

In the La Chona tunnel on the Terneras vein, the C type shows abundant "gray copper" and cupriferous pyrites, contemporaneous with the carbonates.

The average composition of the Terneras ore is, in part:

Au, Grams.	Ag. Grams.	Pb, Per Cent.	SiO_2, Per Cent.	Fe, Per Cent.	CaO, Per Cent.	S, Per Cent.
3.5	835	3.8	39.42	9.36	11.58	4.9

Most of the silver is probably contained in tetrahedrite. The general sequence of metal depositions is as follows:

1. Pyrite and cupriferous pyrite. Chief copper period.
2. Galena and blende. Chief lead and zinc period.
3. Tetrahedrite, highly argentiferous, and also auriferous. Chief silver period.

Taking into consideration the earthy gangues, the succession seems to have been somewhat as follows:

Metallic Minerals.	Earthy Minerals
Pyrite and cupriferous Pyrite.	Undetermined silicate.
	Quartz.
	Mixed Carbonates.
Blende and slightly argentiferous Galena.	
Tetrahedrite.	Mixed Carbonates.
	Calcite.

The Santa Juana and Roca Negra veins, nearby and parallel to the Terneras, contain abundant arsenic, in the form of arsenopyrite, while the Terneras vein contains none. The Santa Juana vein contains also pyrite, cupriferous pyrite, galena, resin blende, jamesonite, and tetrahedrite, the gangue being quartz. A thin section shows jamesonite contemporaneous with cupriferous pyrite. So far as studied in hand specimens, the other minerals also appear contemporaneous. Later than the sulphides is barren chalcedony. Following is a sample general analysis of the ore.

Au, Grams.	Ag, Grams.	Pb, Per Cent.	SiO_2, Per Cent.	Fe, Per Cent.	As, Per Cent.	CaO, Per Cent.	Cu, Per Cent.
7	690	5.9	31.9	20.8	12.3	2.5	1.1

As compared with the Terneras vein (in which arsenic and antimony are absent) there is more gold in the Santa Juana. One assay shows 107 grams gold with only 5.5 grams of silver, and no lead.

In the Caldas vein of the same group the following sequence was observed:

1. Arsenopyrite vein, with subsequent reopening and cementation by

2. Mixed carbonates (containing certainly iron, probably magnesium, etc.) with intercrystallized realgar, probably derived from (1). This vein also contains galena, blende, and barite, but the relations were not observed. Following is a typical single sample

Au, Grams.	Ag, Grams.	Pb, Per Cent.	Zn, Per Cent.
2	1408	9.4	11.2

The position of the arsenopyrite and jamesonite in the sequence of deposition observed in the non-arsenical Terneras

vein has not been fathomed. The arsenical veins of this district are characteristically higher in gold than the non-arsenical ones.

Ore-Deposits of Los Muertos Group.—The Los Muertos Group of nearly vertical veins lie at the edge of the Terneras intrusion, and cut Cretaceous and Tertiary metamorphosed rocks and Tertiary alaskitic volcanics. They are of the same age, apparently, as the veins discussed and really belong in the same group, though they strike northeast. The principal vein is the Los Muertos. Following are samples of the ore:

Au	Ag.	Pb.
4	855	20.6
23	180	.3
29	645	8.8

From this it appears that the silver is largely in the galena, while the gold is independent of it. The sorted ore averages up to 20 per cent. zinc, 18 per cent. arsenic, 12–18 per cent. iron, and 14–15 per cent. lead. The high arsenic and high gold again seem closely connected, and it is suspected that most of the gold is in the arsenopyrite. The earlier metalliferous vein, containing arsenopyrite, pyrite, cupriferous pyrite, blende and galena, has been split open and the opening filled by abundant calcite. Coatings on openings in this calcite are chalcedony. These later veins are barren.

Ore Deposits Connected with the Intermediate Phase of Dioritic Intrusives.

The ores associated with the Guardarraya intrusion usually have the form of definite though not very persistent veins which have formed along strong fractures near and usually paralleling the contact, but of development entirely subsequent to the consolidation of the intrusion. Such veins cut across irregularities in the contact, so as to lie now entirely in the igneous rock, now entirely in the metamorphosed limestone or even in unaltered limestone. In some cases, as in the Guardarraya mine, the channel-fracture is transverse to the contact, and the ore forms in the vein as a shoot at the igneous contact (in the limestone). Lesser but still frequent veins have formed entirely within the

igneous rock, and some entirely within the unaltered limestone, but usually at only a slight distance from the intrusive rock.

In the Guardarraya shoot, the sulphides are pyrite, cupriferous pyrite, galena and blende. The galena is sorted out and shipped. The gangue is mainly quartz, with occasional garnet. These veins are later than the metamorphic belt of garnet rock along the contact. A typical assay follows:

Au, Grams.	Ag, Grams.	Pb, Per Cent.	Zn, Per Cent.	Cu, Per Cent.
1.5	761	7.1	7	.5

The Tiptop is a short vein of a type like the Guardarraya, on a portion of the contact of the Guardarraya intrusion, some 7000 meters from the Guardarraya. A specimen of this ore examined microscopically shows yellow blende, probable arsenopyrite, and a little chalcopyrite, with colorless fluorite, and another undetermined gangue mineral occurring in long needles. The sequence of sulphides is as follows: (1) Pyrite, (2) Chalcopyrite, blende, galena.

Another specimen from the same locality shows contemporaneous cupriferous pyrite, yellow blende, and a little galena, with a gangue of garnet, calcite, apatite, titanite, quartz and adularia, all abundant; also zircon.[1] Some chlorite was observed in patches in the calcite.

A northwest striking vein, entirely in limestone, some 300 meters from the nearest portion of this intrusion, shows under the microscope arsenopyrite and galena, apparently contemporaneous with pyrite and zinc blende. The gangue consists of quartz, calcite, and abundant potash feldspar; also an intensely altered prismatic mineral, possibly originally tourmaline.[2] This mineral is apparently older than the rest. A specimen from a similar vein at a point 160 m. northeast of the first shows galena, dark blende, and arsenopyrite in a colorless fluorite gangue. The galena occurs in veinlets in the blende.

[1] Minerals in this section all checked by Dr. F. E. Wright.
[2] Mineral determined by Dr. F. E. Wright.

Ore Deposits Connected with the Siliceous Phase of the Dioritic Intrusives.

The Copper Queen ore body, containing the principal copper ore of the region, consists of three main pipes or chimneys in metamorphic rock at the contact of the Copper Queen intrusion. The ores here mined are primary, and there is no very great change of nature in depth. The principal sulphides are slightly cupriferous pyrite, blende and galena. The first is undoubtedly predominant, and since when pure it contains several per cent. of copper, it has become available as an ore. Comparing the proportion of metals, however, zinc is probably twice as abundant as copper. Galena is also frequent, and in the upper portion of one shoot it occurs with comparatively little cupriferous pyrites; lower down, the proportion of pyrites increases. The average composition of the ore is:

Au, Grams.	Ag, Grams.	Zn, Per Cent.	Cu, Per Cent.	SiO_2 Per Cent.	Fe, Per Cent.	CaO Per Cent.	S, Per Cent.
.58	175	5.2	2.81	36.5	11.4	17	4.4

The principal gangue is garnet. Garnet, cupriferous pyrite, galena and blende occur apparently intercrystallized; yet abundant veinlets of quartz and sulphides, or calcite and sulphides, or of sulphides alone cut the earlier garnetiferous ore. Galena and blende form seams of this kind much more than does pyrite, indicating a later range of deposition. One thin section shows the following sequence: (1) Garnet, (2) magnetite, hematite, cupriferous pyrite, (3) serpentine ? (chlorite ?) and quartz.

This in the light of the above notes might perhaps be elaborated thus: (1) Garnet, (2) magnetite, hematite, cupriferous pyrite, (3) galena and blende, quartz and serpentine (?) (chlorite?).

SUMMARY OF ORE DEPOSITS ASSOCIATED WITH DIORITIC INTRUSIVES.

We have seen the sequence (pp. 714–715) indicated by successive depositions within the Terneras vein. The gangue of the veins of the Terneras group is principally quartz and car-

bonates, with local sparse silicates to indicate its connection with ores more intimately associated with silicates.

At the Guardarraya, a deposit on the borders of the Guardarraya (intermediate dioritic) intrusion, is an ore very similar to that of the Terneras vein, with the exception that in the latter the chief values are silver and gold while in the former the chief values are in lead. There is also more copper in the former; and though the gangue is quartz, disseminated garnet appears in the Guardarraya. In the Copper Queen deposit, on the borders of the Copper Queen (siliceous dioritic-monzonitic) intrusion, we have chimneys of ore very similar, in respect to the metals present, to the Terneras and Guardarraya deposits, but containing rather less gold and silver, and more copper, with perhaps less lead, and about the same zinc, as compared with these deposits. In these the sulphides have a predominant lime-silicate (chiefly garnet) gangue, but the evidence is that this gangue is (mainly at least) older than the sulphide deposition, which was accompanied by a quartz and calcite gangue.

The succession is then very similar to that in the Terneras region, except that in the Terneras region the products of the two stages have been cleanly separated, while in the Copper Queen they have been intermingled, or superimposed one upon the other. At the Copper Queen, also, magnetite and hematite occur apparently contemporaneous with the cupriferous pyrite.

The veins which were noted above (pp. 718–719) as associated most nearly with the intermediate dioritic phase (but which are relatively near the Copper Queen mine), show orthoclase (adularia), garnet, titanite, apatite, zircon, chlorite, quartz, calcite and fluorite as gangues; while the sulphides embrace arsenopyrite, pyrite, cupriferous pyrite, blende and galena. Here we have in addition to the characteristic lime-silicate of these ore-deposits (garnet) almost a complete list of the minerals characterizing the most siliceous of the recognized "igneous rocks." Indeed, when we compare the list of these last-named gangue minerals, with that of the later-crystallized components of the associated igneous rocks (pp. 704–5) we find an almost complete coincidence; and when we come to draw up a scheme of the

whole district, we become aware of a large overlap of "mineralization" stages upon "igneous rock crystallization" stages, suggesting strongly that where they thus coincide they are one and the same thing.

For the mineralization we may, in résumé, make a rough attempt at sketching the successive stages, beginning with the earliest. These stages freely overlap one upon the other.

1. Orthoclase, titanite, apatite, zircon, chlorite, fluorite.
2. Garnet.
3. Cupriferous pyrite, quartz and calcite.
4. Blende and galena, in the approximate order named.
5. Tetrahedrite (argentiferous and auriferous), quartz.
6. Mixed carbonates and calcite.
7. Calcite.

Joining this with the sequence determined by the study of the associated rock (pp. 704–5) we may make the following rough divisions of crystallization:

A. Andesine-oligoclase and some hornblende.

B. Magnetite, biotite, and grass-green pyroxene.

C. Orthoclase, apatite, titanite, chlorite, quartz, pale-green pyroxene, pyrite, chlorite, fluorite, zircon.

D. Garnet and pale-green to colorless pyroxene.

E. Cupriferous pyrite, pyrite, quartz and calcite.

F. Blende and galena.

G. Tetrahedrite (argentiferous and auriferous), quartz and mixed carbonates.

H. Quartz and mixed carbonates.

I. Calcite.

At any one point, numerous gaps in the representation of these stages commonly occur; and typically the general character of an ore-deposit depends upon the relative representation of various stages.

ORE DEPOSITION CONNECTED WITH ALASKITIC INTRUSIONS.

Ore Deposition Connected with Alaskite Intrusions.

Around the alaskite intrusions of the Santa Maria range, the belt of altered limestone consists largely of garnet and py-

roxene, with quartz and calcite, specular iron, and sulphides such as pyrite, cupriferous pyrite, zinc blende, and occasional galena. Specimens[1] show the following general sequence of crystallization: (1) Garnet, pyroxene, and vesuvianite, (2) specularite and pyrite, (3) pyrrhotite, quartz, and cupriferous pyrite, (4) blende, serpentine (?) and pale-green amphibole appear to be later than (1). Locally these contact materials contain so much copper as to form small and irregular bodies of low-grade copper ore. Other similar bodies run high in zinc (blackjack). Argentiferous galena is also found in small quantities.

The lead-zinc-silver (argentiferous galena-blende) ores usually occur along definite post-intrusion fractures. At the Bonanza mine, for example, a north-south vein is traceable 300 meters in limestone and across the tip of an alaskite intrusion. At the two points where the fracture zone strikes the alaskite contact, the two principal shoots of galena ore have formed in the limestone.

No large ore-bodies have been found at or near the contact of the simple alaskite phase of the alaskitic intrusions.

Ore Deposition Connected with Trachytic Alaskite Intrusions.

The contact alteration associated with the trachytic alaskite intrusions is marked by a less amount of silicate minerals and quartz, as compared with that attending the alaskite proper. Fluorite is frequently encountered in and on the contact of the main trachytic alaskite intrusion, but is rare in the alaskite. The trachytic alaskite contact is also marked by less copper, and frequently a far greater amount of lead, zinc, and silver. Amounts of these metals large enough to constitute actual or possible ore frequently occur along the trachyte contacts, with or without an attendant belt of metamorphic silicate minerals. Frequently large amounts of pyrite, argentiferous galena, and blende have been deposited, while lime-silicate minerals have developed sparingly or not at all. The maximum lead-zinc-iron sulphide bodies have been found along the contacts of a narrow trachytic alaskite dike, for a distance of about a thousand meters. Lesser veins occur in limestone, but nearly always

[1] See page 709.

within a maximum of one or two hundred meters from an intrusive contact. These contact veins, as well as the veins in limestone, have formed along channels produced by movement or slipping along and near the contacts, subsequent to intrusion. Hence the veins locally cut through or occur within the intrusions, or follow faults which have displaced them.

The ore-bodies of the Santa Maria consist of blende, argentiferous galena, and pyrite. The pyrite is locally slightly cupriferous, also locally slightly arsenical. The gangue mineral is quartz; in only a single locality have lime-silicates been found. Here a thin section[1] shows the following sequence: (1) Garnet, calcite and quartz, (2) pyrite and zinc blende.

RELATIONS OF SAN LORENZO AND SANTA MARIA ORE-DEPOSITS.

The dioritic and the alaskitic intrusions were substantially contemporaneous; and the ore deposits of the San Lorenzo and Santa Maria ranges appear to have immediately succeeded the intrusion period, with an intermediate and overlapping stage marked principally by the deposition of lime silicates. In both the Santa Maria and the San Lorenzo ranges there are great fault fissures, plainly identical in age, filled with the peculiar barren calcite which in the case of the Terneras vein is held to be the last stage of vein formation. Apparently, then, the mineralization was contemporaneous in both ranges. There is in the Santa Maria range no trace of transition between the crystallization of the igneous rock and that of the metamorphic period, such as is found in the San Lorenzo range; there is indeed in the Santa Maria a hiatus between the crystallization of the fine-grained alaskites and the contact metamorphic crystallization. There exists, however, in the Santa Maria range a consecutive chain between the ore-deposits associated with lime silicates and the more important ones having a quartz gangue; and stages of mineralization are recognized similar to those in the San Lorenzo range. The Santa Maria deposit of pyrite (sometimes slightly cupriferous and arsenical), argentiferous galena, blende and quartz belongs essentially to the F period of the San Lorenzo veins (on p. 721), with a slight overlap back on the E period.

[1] See page 709.

SUMMARY OF IGNEOUS PHENOMENA AT VELARDEÑA.

1. About the middle of the Tertiary, andesitic eruptions broke through the Cretaceous limestones of the district.

2. After a considerable interval of geologic time, intrusions of dioritic rocks, varying from basic to siliceous in composition, broke up through the limestones; nearby, there were intrusions and surface eruptions of alaskite. Basalt occurs also on the edge of the district. These various rocks are believed probably to represent the result of differentiation of the magma represented by the andesite.

3. Subsequent to the last intrusions, fractures were formed around, in and on the margin of intrusions; and lime silicates, chiefly garnet and pyroxene, were deposited, chiefly by alteration of the existing rocks. The solutions depositing these plainly ascended along the intrusive necks. The minerals deposited were strikingly similar everywhere, varying very little with the composition of the associated intrusive rock, though more with the character of the rock attacked; and they are believed to have been deposited from solutions representing a residual highly siliceous and aqueous magma.[1]

4. Sulphides began to be deposited with the lime-silicates, but the chief sulphide deposition followed the lime-silicate period directly, with quartz as principal gangue. The sulphide deposition showed various brief and intense stages, illustrated by the predominance of different metals. The metalliferous period was then followed by the deposition of barren quartz and mixed carbonates; and this by abundant barren calcite. The different stages of deposition are believed to follow a regular law, and to represent successive precipitations from a magma residual from that which deposited the lime-silicates. Like the last-named magma, the metalliferous magma arose along fractures in and along the contact with the intrusive necks; but the resulting ores seem

[1] It is believed that the magma in its later stages acquired additional lime through solution of limestone. The grounds for this belief rest upon evidence observed in other mining districts, and this evidence it is hoped to present later.

to depend very little upon the chemical character of the associated rock.

5. It is believed that from a solution carrying lime and silica, lime-silicates will be deposited under conditions of great heat, and from the same solutions at a lower temperature, quartz and lime carbonate will be deposited; so that the passage from the one type of gangue to the other signifies deposition at a lowered temperature and at a greater distance from the source of the solutions. Similarly the whole sequence of a crystallization is believed to have been attended by, and to have resulted from, a constantly lowering temperature.

It follows that from crystallizing magmas, the deposition of metallic sulphides takes place at a definite stage, and the different metals are precipitated in a definite order.

THE NEWARK COPPER DEPOSITS OF SOUTH-EASTERN PENNSYLVANIA.[1]

EDGAR T. WHERRY.

INTRODUCTION.

The group of rocks representing the Triassic Period in eastern North America, now generally known as the Newark Series, is marked throughout its entire range by three peculiar characteristics—general lithological similarity over broad areas, universal presence of great masses of trap, and frequent occurrence of copper deposits.

This last feature has attracted attention since the time of the earliest settlements, and large sums of money have been wasted in the endeavor to obtain and utilize the apparent underground wealth. Geologists, of course, have not overlooked the existence of these ore bodies, but while those of New Jersey have been repeatedly discussed in the reports issued by the state,[2] the equally interesting occurrences in Pennsylvania have never received adequate study.[3] A slight contribution to the subject may therefore, it is hoped, prove acceptable.

HISTORICAL SKETCH.

It is frequently asserted that the Schuyler Mine, at Arlington, N. J., was the first to be operated in America, and by mere repetition this statement has gradually gained acceptance, being reaffirmed by Professor Lewis in the paper above referred to. As a matter of fact there is the best of reason to believe that

[1] Read at the meeting of geologists at the New York Academy of Sciences, April 6, 1908.

[2] More especially in the Annual Reports for 1902 and 1906; compare also Professor J. Volney Lewis: "Copper Deposits of the New Jersey Triassic," ECONOMIC GEOLOGY, II., 1907, pp. 242–257.

[3] But one important paper has been published: Mr. B. S. Lyman, "Copper Traces in Bucks and Montgomery Counties," *Journal of the Franklin Institute*, Philadelphia, CXLVI., 1898, 416–423.

some four or five mines had been opened, and even extensively worked, long before 1719, when the Arlington deposit was discovered.

The brilliantly colored chrysocolla and malachite were probably highly prized and eagerly sought by the Indians for use as pigments. And the colonists no doubt soon recognized the true character of these materials, and induced the natives to guide them to the localities from which they were obtained. The early discovery of copper ores in the various colonies is thus easily explained.

The Dutch were the first to begin actual mining operations, three distinct enterprises being mentioned in the records: Ellenville, Ulster County, N. Y.; Menesink, Warren County, N. J., nine miles above the Delaware Water Gap; and Bowman's Hill, south of New Hope, in Bucks County, Pa. Which of these mines was opened first is not certainly known, but they all date back at least to 1650.[1]

Turning to New England, we find that in Massachusetts a mine was opened by Governor Endicott in 1651, and in Connecticut the famous Granby or Symsbury mine was started about 1709 and was being actively worked in 1718.

Finally, there is one other mine, more directly connected with the present discussion, which can probably claim precedence over the Schuyler Mine, namely the Old Perkiomen Mine, at Schwenksville, Pa. In 1683, two years after landing in this province, William Penn wrote to friends in England of the existence of "mineral of copper and iron in divers places." And his agents granted the tract of land, upon which this mine is situated, as early as 1703.

Operations were apparently begun soon afterwards, for in the "Breslauer Kunst und Natur Geschichten," supplement III, p. 46., (1725) it is stated that prospecting had been carried on for several years, and much good ore had been discovered. After several unsuccessful attempts a German mining engineer, Christopher Geist, was brought over to carry on the work, and under

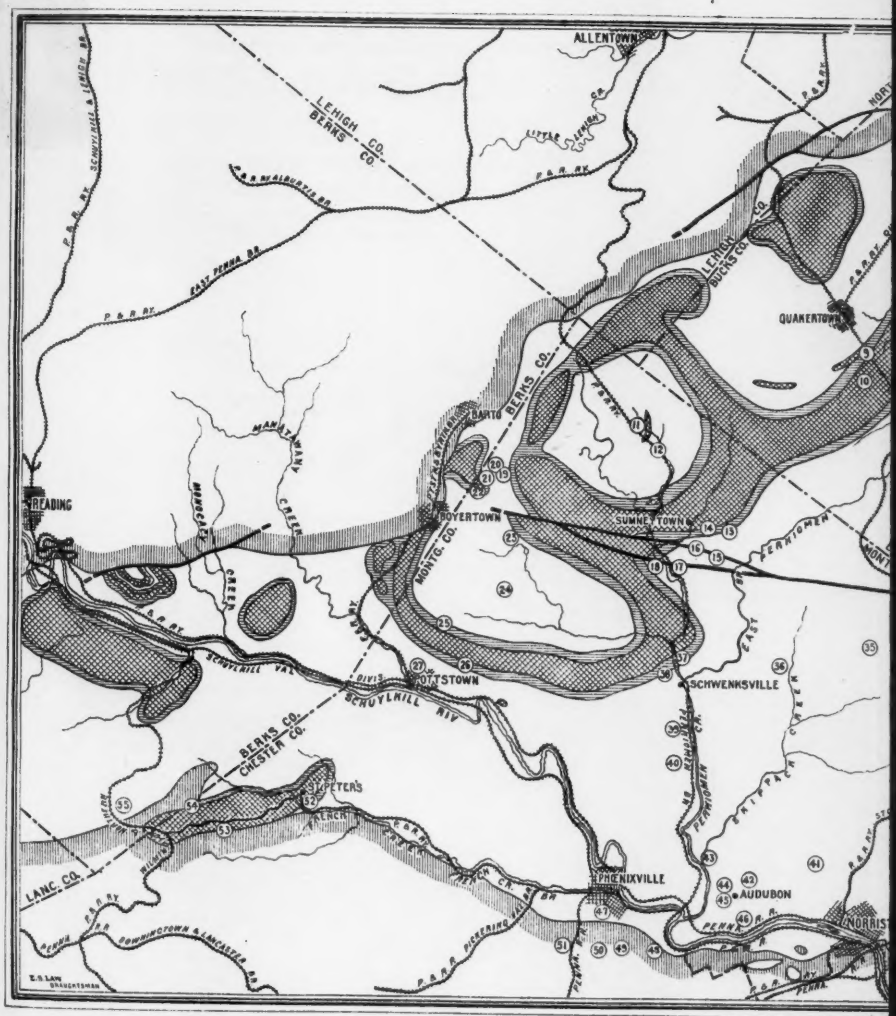
[1] A full discussion of this question, with references to the literature, has been published in the *Journal of the Franklin Institute*, Philadelphia, CLXVI., 1908, 309–314.

KEY TO LOCALITIES ON PLATE XIII.

The numbers at the left-hand correspond to those enclosed in the circles on which division the deposit belongs. Thus: 1a = Deposits in trap rock. 1b = Deposits in metamorphosed sediments near trap sheets. 1c = Deposits in fissures intersecting trap sheets. 2 = Of deep-seated origin apart from visible trap. 3 = Of sedimentary origin.

1. Prospect, 1 m. S. W. of Lodi.. 1b
2. Tettemer's mine, 1 m. W. of Uhlerstown 1b
3. Exposures, S. W. of Uhlerstown. 1b
4. Roadside, S. of Kintnersville.. 1b
5. Roadside, N. of Ferndale..... 1b
6. Roadside, ¾ m. S. E. of Bursonville 1b
7. Prospect, near Keller's Church. 3
8. Roadside, ½ m. S. W. of Hagersville 3
9. Railroad cut, 2 m. S. E. of Quakertown 1b
10. Diehl's gold mine, ½ m. N. W. of Rock Hill..... 1a
11. Roadside exposure, ¼ m. N. E. of Pennsburg 1b
12. Railroad cut, ⅜ m. N. W. of Red Hill 3
13. Roadside, 1½ m. E. of Sumneytown 1b
14. Roadside, 1 m. E. of Sumneytown 1b
15. Kober's mine, ¾ m. N. E. of Woxall 1c
16. Karl's mine, ½ m. N. W. of Woxall 1c
17. Railroad cut, ½ m. N. of Hendricks 1c
18. Young's mine, ⅜ m. N. W. of Hendricks 1c
19. Hillside exposure, ¾ m. N. E. of Congo ..... 1?
20. Bauman's platinum mine, ¾ m. N. W. of Congo..... —
21. Roadside exposure, ½ m. N. W. of Congo 1b
22. Quarry, ½ m. W. of Congo.... 1a
23. Brendlinger mine, 1 m. S. W. of Sassamansville ..... 1?
24. Roadside, 3 m. E. of Gilbertsville 3
25. Roadside, 1½ m. S. of Gilbertsville 1b
26. Pennsylvania Copper Co.'s mine, 2 m. N. E. of Pottstown.... 1b
27. Prospect and roadside exposures, N. and W. of Pottstown ..... 1?
28. Roadside, 1 m. W. of New Hope ..... 1?
29. Prospect, 1½ m. W. of New Hope ..... 1?
30. Solebury mine, west end of Bowman's Hill 1c
31. Barite mine, ½ m. W. of Buckmanville 1c
32. Exposures, 3 m. W. of Buckmanville (barite) 1c
33. Four mines, S. E. of New Galena 2
34. Two mines, ¾ m. S. W. of New Galena 2
35. Exposures north of Drake's Corner 3
36. Quarry, 1½ m. E. of Lederachsville 3
37. Exposures and prospects N. of Schwenksville 1b
38. Old Perkiomen mine, ½ m. N. W. of Schwenksville 1b
39. Prospect at (?) Grater's Ford. 3
40. Quarry, ¾ m. N. of Collegeville 3
41. Prospect, 1 m. E. of Fairview. 2
42. Prospect, N. E. of Audubon.... 2
43. Field near mouth of Skippack Creek 2
44. Perkiomen mine, ⅜ m. N. W. of Audubon 2
45. Ecton mine, ⅜ m. W. of Audubon 2
46. Prospects east of Betzwood and Port Kennedy 2
47. Morris mine, ½ m. S. of Phœnixville 2
48. Napoleon mine, 1¼ m. W. of Valley Forge 2
49. Wheatley, Brookdale, and Chester County mines 2
50. Montgomery mines, etc., all 2 m. S. of Phœnixville 2
51. Charlestown and Buckwalter mines, 1 m. N. E. of Charlestown 2
52. Elizabeth mine, south of St. Peters 1b
53. Warwick mine, south of Warwick 1b
54. Hopewell mine, 1 m. N. W. of Warwick 1b
55. Jones mine, ¾ m. E. of Joanna. 1b

PLATE XIII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LEHIGH
BUCKS CO.
QUAKERTOWN
BERKS CO.
PENN
BARTO
MANATAWNY
MANATAWNY CREEK
FRITZ TOWNSHIP
READING
MONTG. CO.
BOYERTOWN
SUMNEYTOWN
PERKIOMEN
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MACUNGIE CREEK
SCHUYLKILL VAL
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POTTSTOWN
SCHWENKSVILLE
EAST
BERKS CO.
CHESTER CO.
PETER'S
CREEK
PERK
LANC. CO.
PHOENIXVILLE
AUDUBON
NORRIS
PERKIOMEN
SAUCON CREEK
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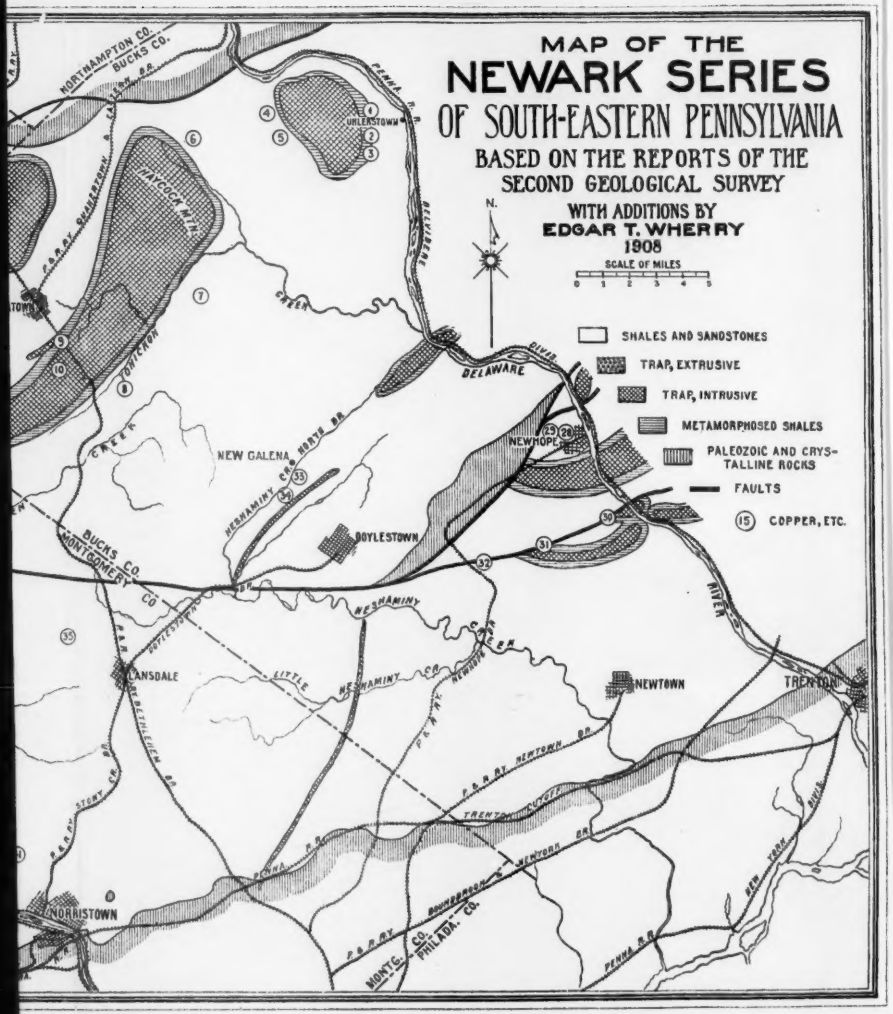

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his direction the shafts and tunnels visible to this day were constructed. All of the ore obtained was exported to England; that it was considered valuable is shown by its inclusion among the principal products of the Province in Whitworth's Account of the trade of Great Britain, published in 1776. Finally, when the Revolution broke out, the mine was abandoned, and practically forgotten, having completely escaped the notice of the geological surveys of the state.

The other mines of the Newark in Pennsylvania are of comparatively recent date, so that no separate sketch of their history seems called for. Instead, we may proceed to the study of the character and relations of the various copper deposits.

GEOLOGY OF THE REGION.

The accompanying geological map, Plate XIII, illustrates the geology of the region. The location of the mines is shown by circles enclosing figures.

The rocks of the Newark Series extend across Southeastern Pennsylvania in an irregular strip, over thirty miles wide at the Delaware, but narrowing westward to less than ten below Reading. The statement made in Chamberlin and Salisbury's "Geology"[1] that a classification corresponding to that of New Jersey has never been applied here is incorrect; in the Summary Final Report of the Second Geological Survey, Volume 3, Part 2 (1895), was published a report on the region by Mr. Benjamin Smith Lyman, in which five subdivisions were described, the lower three being identical with those announced several years later in New Jersey, and the upper two being practically absent in the latter state. The priority of the Pennsylvania names will justify their use in the present paper.

These subdivisions, beginning at the bottom, are the Norristown, arkose sandstone and conglomerate, with some red shale; the Gwynedd, hard, dark-colored carbonaceous argillite; the Lansdale, bright red and quite soft shale; the Perkasie again a hard and dark-colored rock; and the Pottstown comprising red shale, and near the border, sandstone, conglomerate, and breccia. The

[1] Volume 3, page 10.

aggregate thickness of these formations is probably in the neighborhood of 20,000 feet.

The structure is in general monoclinal, with a gentle northwest dip, but toward the northern boundary there is a series of folds, with axes at right angles to the general direction of strike of the formation. A great fault, or rather, a system of faults, extends across the region, the maximum throw, near the Delaware, being about 10,000 feet; to this is due the widening of the field to the eastward. The northern boundary is also in part determined by faults, and a number of minor ones have been noted in various places.

Trap is abundantly exposed over wide areas, but has received in the past comparatively little study. Mr. Lyman, in the report cited, describes several sheets as extrusive, basing this conclusion on their general conformity with the sedimentaries. The writer has carefully examined all of these sheets and has been able to discover but one that is certainly extrusive, in Berks County, five miles southeast of Reading.[1] The evidence in this case consists in the vesicular character of the rock, and the complete absence of alteration in the enclosing shales. The intrusive character of the remainder is proved by their lack of vesicular structure, the coarseness of their constituent minerals and the intense metamorphism which they have produced in the overlying as well as the underlying sedimentary rocks. This metamorphism is rather variable in extent, reaching a maximum at the Perkiomen Creek; here, both above and below the great Haycock trap sheet, which is perhaps a thousand feet thick, the shales are strongly indurated and changed in color to a thickness of 500 feet, and a distinct effect is perceptible at 800 feet from the contacts.

DESCRIPTION OF THE COPPER DEPOSITS.

The various modes of occurrences of the ores may be conveniently classified as follows:

[1] On the accompanying map the extent of this sheet, and its distance from the intrusive one surrounding it, have been somewhat exaggerated so that the true relations might be more clearly brought out.

1. Associated with igneous rocks.
(*a*) In trap rock.
(*b*) In metamorphosed sediments near trap sheets.
(*c*) In fault-fissures intersecting trap sheets.
2. Of deep-seated origin, apart from visible trap.
3. Of sedimentary origin.

The location of all of the known occurrences of copper in the region under consideration is shown in the accompanying map, Plate XIII.

1. ORES ASSOCIATED WITH IGNEOUS ROCKS.

The igneous rocks of the Newark series are generally recognized to contain small amounts of copper, which occurs both as distinct specks of sulphide and as a constituent of the dark silicates. At one locality in our region a notable quantity of chalcopyrite is found in a segregation in a small trap sheet, but such a condition is exceptional, and only the barest traces of copper have been observed in the trap elsewhere.

On the other hand, as may be seen on the map, the metamorphosed sediments in the vicinity of the igneous masses show copper at many points. The metal has evidently been brought to its present position by the heated waters which produced the alteration, and it seems quite probable that its ultimate origin lies in the trap itself and that it has been given off during the solidification and cooling of the latter, as suggested by Professor Lewis in connection with similar occurrences in New Jersey.

As to the minerals represented, bornite and chalcopyrite are by far the most prominent, the chalcocite and native copper so characteristic of the New Jersey deposits being here extremely rare. Both chrysocolla and malachite are abundant, chiefly as alteration products, the latter being the more frequent, on account of the calcareous nature of the shales in which the ores are usually situated.

The sulphides commonly occur in minute globular or elongated grains which at first sight appear to result from the filling of cavities left by the dissolving out of specks of calcite, as has

occurred at Somerville, N. J., but closer examination shows that they represent, rather, concretionary masses, enclosing particles of sediment, after the fashion of clay-stones, sand crystals, or, more nearly still, the epidote nodules with which they are often associated.

The principal cause of precipitation here, as in New Jersey, seems to have been the decrease of temperature and pressure as the solutions ascended, or of temperature alone as they descended below the trap. Of the other possibilities described by President Van Hise,[1] mingling of solutions may have contributed, in the fault-fissure deposits, at least, but in no case has certain evidence of reaction with the sedimentary rocks been detected. In a few instances, to be sure, organic matter has caused accumulation of copper, but these are all examples of ores of sedimentary origin, and are discussed under that heading.

(*a*) *Ores in Trap Rocks.*—In a trap sheet near Congo, Montgomery County (loc. 22),[2] chalcopyrite appears in large irregular grains embedded in seams of fibrous hornblende. Some years ago this material was announced as gold-bearing, and the writer made an assay of it, finding .3 ounce of that metal and 1.7 ounces of silver. As these values are probably confined to the chalcopyrite, which constitutes less than 10 per cent. of the rock, this mineral would appear to be extremely rich. But the amount of the "ore" is limited, and profitable working seems out of the question.

In this connection the occurrence of gold in trap at another point is worthy of mention. In the Haycock sheet near Rockhill Station, in Bucks County (loc. 10), there is a small area of unusually coarse-grained diabase (gabbro) in which a find of 3½ ounces of gold to the ton was reported in the local newspapers. It developed later that this was a fraud, but, strange to say, the rock actually did prove to contain gold, assays made under the writer's direction, upon material collected by himself,

[1] "A Treatise on Metamorphism," U. S. Geol. Survey Mon. XLVII., pp. 1081–1088.

[2] The numbers refer to the map, upon which each locality is designated by a circle, with figures within.

yielding about $1.00 to the ton. Reports of gold, silver and platinum elsewhere have, however, in every case turned out to be false.

(*b*) *Ores in Metamorphosed Sediments near Trap Sheets.*— The hard gray shales flanking the trap ridges frequently show traces of chrysocolla or malachite in flakes and coatings over the bedding planes and joint cracks. These minerals are probably always secondary, as wherever extensively exposed, they are seen to be derived from sulphides disseminated through the rock. Although usually very limited in amount, such ores have, in three different places, presented a sufficiently attractive appearance to have occasioned the opening of mines.

Along the east slope of the plateau known as "The Swamp" in northeastern Bucks County, a stratum of shale-bearing copper in this manner can be traced for a distance of three miles by roadside exposures and bleached spots in the fields. During the past thirty years prospecting has been carried on at various points, one shaft (loc. 2) being sunk, it is said, to a depth of 80 feet; but only the barest traces of ore have so far rewarded these efforts.

The history of the old Perkiomen Mine (loc. 38), half a mile northwest of the town of Schwenksville, which is also an example of this type of deposit, has already been described. In the dumps around the shafts on top of the hill, the dark shales contain patches and lenses of bornite and are extensively coated with chrysocolla, and traces of cuprite and malachite. A curious case of resemblance was noted here in the presence of aggregates of a bronzy biotite, which, with the naked eye, could not be distinguished from the bornite! This visible material would certainly be unworkable, but, as has already been stated, there is reason to believe that the mine at one time yielded profit to its owners.

North of Pottstown, green-stained rocks have frequently encouraged mining operations, and at one place (loc. 26) a furnace was actually erected a few years ago and an attempt made to smelt the ore. This consisted of somewhat fractured dark gray

shale with thin films of chrysocolla, averaging perhaps 0.5 per cent. of copper, and of course the undertaking failed.

The old iron mines of the French Creek region (locs. 52–55) also belong in this group, but as they have been fully described in the reports of the Pennsylvania Surveys, and as copper minerals were never obtained in any considerable amount, no special description of them need be introduced.

(*c*) *Ores in Fault-Fissures Intersecting Trap Sheets.*—It is generally recognized that the greater part of the deformation and faulting which the Newark rocks have undergone took place subsequent to the intrusion (and extrusion) of the trap. But the occurrence at several places in the Pennsylvania region of fault-fissures along which metamorphic effects are noticeable at considerable distances from trap masses, in the midst of comparatively unaltered shales, suggests that here, at least, faulting occurred during, or immediately subsequent to, the intrusion. For, as already stated, the development of secondary epidote, garnet, tourmaline, etc., as well as the introduction of the frequently associated copper ores, is most reasonably attributed to the action of the heated waters given off during the solidification and cooling of the trap. And although these solutions penetrate for considerable distances through the undisturbed rocks, they can circulate most readily, and produce the most far-reaching effects, through the brecciated zones of fault-fissures.

On Abraham Kober's farm (loc. 15), one mile northeast of Woxall, several shafts were sunk in deposits of this kind about 1875. The dumps show crushed and slickensided fragments extensively altered to epidote, with chalcopyrite in narrow veins, streaks, and scattered grains. There is also a little bornite, and a great display of secondary azurite, chrysocolla, malachite, melaconite, and, rarely, native copper. At Karl's mine (loc. 16), situated on the same fault line about a mile to the west, the conditions are quite similar to those at Kober's, except that the principal secondary silicate is brown garnet instead of epidote. In the cut of the Perkiomen Railroad, north of Hendricks Station, several parallel faults of horizontal throw are visible and near

the principal one (loc. 17) the limestone of the Perkasie formation contains specks of chalcopyrite and coatings of malachite. On the west bank of the creek, just opposite, a stock company headed by Mr. William F. Young opened a mine about five years ago, sinking a shaft 150 feet deep, and obtaining ore of the same character as that from the other places.

All of these mines are now abandoned, full of water, and inaccessible, the obvious reason being that the ores were too small in quantity. If, however, the "veins," or zones of rock impregnated with sulphides, are, as described by those who worked in the mines, a foot or more in thickness, and if they can be followed along the fault lines without decrease in size, or metal content (which averages over 30 per cent.) there seems no reason why working should not be profitable. On the other hand, the failure of the far more extensive deposits at Audubon and at some of the New Jersey localities suggests caution, and further exploration is desirable before any final statement as to the value of the properties is made.

The discovery of copper by the Dutch at Bowman's Hill, south of New Hope, has already been noted in the historical sketch. The old openings are still accessible and fragments of rock on the dumps show bornite and chrysocolla. The deposit (loc. 30) is situated in the metamorphosed shales overlying a small intrusive trap mass, and may be connected with the branch of the great fault which runs through the valley to the north.

For several miles westward, the course of this fault is traceable by deposits of barite, which outcrop along streams and roadsides as far as locality 32, and have been worked at one point, near Buckmanville (loc. 31). The material exposed here in a breccia of trap and sandstone fragments, cemented together by crystalline barite, with small quartz crystals and occasional specks of chalcopyrite. The exact source of this barite is not certain; it may either represent a segregation from the trap mass, or have been derived from the underlying limestone; but its relation to the fault line is at least worthy of notice.

2. ORES OF DEEP-SEATED ORIGIN APART FROM VISIBLE TRAP.

At three places in the region under discussion, there occur fissure-vein deposits of a very different type from those just described. The distinguishing features are the absence of igneous rocks,[1] the presence of ores of lead and zinc along with the copper, the abundant development of gangue minerals such as quartz, ankerite and fluorite, and the appearance of a banded or "crustified" structure.

In the Phœnixville and New Galena districts copper minerals are present only in small quantities; at Audubon, however, the copper was the only metal sought, the zinc and lead so prominent at the other mines being here subordinate in amount. In comparing the deposits of this locality with those at Phœnixville, and the separate mines at the latter place with one another, Henry D. Rogers was led to the conclusion[2] that "such of these veins as are confined entirely or chiefly to the gneiss bear lead as their principal metal, whereas those which are included solely within the red shale are characterized by containing the ores of copper." He seems to have regarded this as an example of the influence of the wall rock upon the character of deposit, but it is more probably only an illustration of the tendency of various metals, in the rise of the depositing solutions, to separate into definite vertical zones, which has been emphasized by Mr. J. E. Spurr in his recent theory of ore deposition;[3] the lead and zinc having deposited in the underlying gneiss, while the copper ascended into the Newark shales and sandstones.

The deposits of this class, being the richest in the region, have already received considerable attention from geologists, and as they are not peculiar to the Newark series, need but passing mention here. The Phoenixville mines were opened about 1800 and being in active operation at the time of the first Pennsylvania Survey, were carefully studied and accurately described

[1] The trap dikes noted in a few cases were of subsequent formation, since they are observed to cut the ore bodies.

[2] Report on the Wheatley mines, 1853; "Geology of Pennsylvania," 1858, II., p. 699.

[3] ECONOMIC GEOLOGY, II., 1907, p. 790.

by Rogers.[1] They were abandoned in the fifties, having never really proved a paying investment. The mines of the Audubon (Shannonville) district, as noted by Professor O. C. S. Carter,[2] had a similar history, while the occurrences in the New Galena district are still less promising and attempts at mining there have repeatedly failed.

3. ORES OF SEDIMENTARY ORIGIN.

Small deposits of copper are occasionally found in unaltered shales, miles away from any mass of trap or line of fracture, and to them it seems necessary to assign a sedimentary origin. A typical occurrence of this class is the one near Drake's Corner (loc. 35); here in the midst of bright red Lansdale shales, well exposed in a roadside cutting, is a greenish gray layer, about a foot thick, in which the bedding planes are thickly coated with malachite. Again, in the railroad cut south of Pennsburg (loc. 12) grains of chalcopyrite, and malachite from their alteration are embedded in a thin stratum of shaly limestone in the Pottstown formation. And finally, in the University of Pennsylvania collection there are specimens from Graters Ford (loc. 39), where the conditions are similar, presenting the additional feature of plant remains around which the copper has collected, in the form of chalcocite.

Copper ores of sedimentary origin have been described from many places. It has been regarded as singular that the Permian strata of various regions—Texas, Nova Scotia, Germany, Bohemia, Russia—contain such deposits. It appears, however, that they are not peculiar to the Permian, but occur in all formations of the "red-beds" type.[3] In Pennsylvania, for instance, they have been observed in the Schwangunk ("Medina-Clinton") red shales and sandstones and at several horizons in the Upper Devonian and Mississippian, as well as in the Newark.

[1] *Loc. cit.*

[2] Bean's "History of Montgomery County, Pennsylvania," Philadelphia, 1884, p. 9.

[3] Compare Mr. S. F. Emmons: Copper in the Red Beds of the Colorado Plateau Region, Bulletin U. S. Geol. Surv., pp. 221–232; Mr. Waldemar Lindgren: Bull. U. S. Geol. Surv. 340, pp. 170–174.

The crystalline rocks from which the materials of these later beds were derived contain copper minerals at many points. At the present day, the metal passing into solution, as weathering takes place, finds its way into the sea. If the climate were, however, sufficiently arid so that the streams would either dry up as they flowed or terminate in small lakes, concentration of this copper might readily occur to such an extent that accumulating organic matter could bring about its precipitation. The presence of such copper deposits is therefore in agreement with the modern conception of a semi-arid, continental origin for the rocks of the Newark series and other similar formations.

The writer is glad to acknowledge his indebtedness to Mr. E. Stanley Law, for the skill and care he has expended upon the accompanying map; to Dr. Florence Bascom for the use of her unpublished maps of the region; and to Dr. Amos P. Brown, Mr. George W. Geist and Mr. Benj. Smith Lyman for valuable assistance in the preparation of the paper.

SOME COPPER DEPOSITS IN THE SANGRE DE CHRISTO RANGE, COLORADO.

RUFUS MATHER BAGG, JR.

LOCATION.

The Sangre de Christo Range lies near the south central portion of Colorado. It forms the western boundary of Custer as well as portions of Huerfano and Fremont counties and rises to great elevation. At its southern extremity is the loftiest mountain in the state, Blanca Peak, whose crest breaks the sky line at 14,463 feet above sea level.

The range is about seventy-five miles long with a narrow somewhat flexed axis trending northwest. Two nearly parallel ranges, Park and Saguache, rise to the north and northwest. In a spur of the former, Mosquito range, lies the great mining centre Leadville. The Greenhorn mountains to the east, are separated from the Sangre de Christo by the fertile, narrow, Wet Mountain Valley, and curve in toward the base of the Sangre de Christo Range in their southward extension. See Fig. 66.

GEOLOGY.

DESCRIPTION OF THE RANGE.

The literature on the geology of this interesting uplift is somewhat limited, presumably because while the age and general geologic features have long been recognized, no great mining centres have yet been developed.

Professor Van Hise in his "Correlation Paper on the Archean and Algonkian"[1] gives a brief list of some references relating to the Sangre de Christo Range which are instructive.

Hayden's early "Survey of the Western Territories of the United States" includes a superficial examination of the structure of the range. This examination, carried on under direction of

[1] Bulletin No. 86, U. S. Geol. Surv., pp. 313, 314.

Mr. F. M. Endlich, was published in the Annual Report for 1873.[1] According to him the range consists of an immense thickness of paleozoic sediments, chiefly sandstones, underlain by Carboniferous limestone. This entire mass of sediments, over a mile thick, rests on granite of a different type from that composing the Pike's Peak area to the northwest. Endlich found this granite along the summit of the uplift and says: "It crops out all along the crest of the range as far as could be determined with the single exception of a place between stations 19 and 20, where the sedimentary rock making up the greater part of the range forms a bridge." An examination of Endlich's diagram of his section work makes it clear that he refers to the region near Rito Alto peak. (Fig. 65, page 741, from Endlich's Report, U. S. G. S. Terr., 1873.) In July, 1907, the writer made an examination of this area to determine if possible the nature of the sediments lying beneath the sandstone of Rito Alto peak and to ascertain whether they had any bearing upon the mineralization of the Rito Alto and adjacent Copper prospects.

Rito Alto Peak is about 13,000 feet high (12,989 Hayden) and it is not far from the centre of the uplift of the Sangre de Christo Range. The entire mass of Paleozoic sandstone capping this mountain has been lifted into an immense anticlinical fold with its axis near the present summit of the mountain. At the crest the strata stand nearly vertical, and dip away more and more gradually down the adjacent slopes, until, at the base of the mountain proper, the angle of dip varies from ten to fifteen degrees from the horizontal.

This major anticline has been broken by parallel and cross faults in the vicinity of Rito Alto which are partly concealed from view by surface weathering of the sandstone aided by a heavy growth of spruce timber which extends to an altitude of about 11,500 feet. Above this timber line some minor peaks occur near the main Rito Alto major anticlinical uplift which show the Carboniferous strata dipping at various angles to the slopes of the larger fold. These outliers southwest of Rito

[1] Ann. Rept. U. S. Geol. and Geog. Surv. Terr., 1873 (1874), pp. 305-351.

Alto Peak are the results of the parallel and cross faults above mentioned.

The width of the Sangre de Christo uplift as compared to its height is remarkably narrow and gives the range scenery of imposing grandeur.

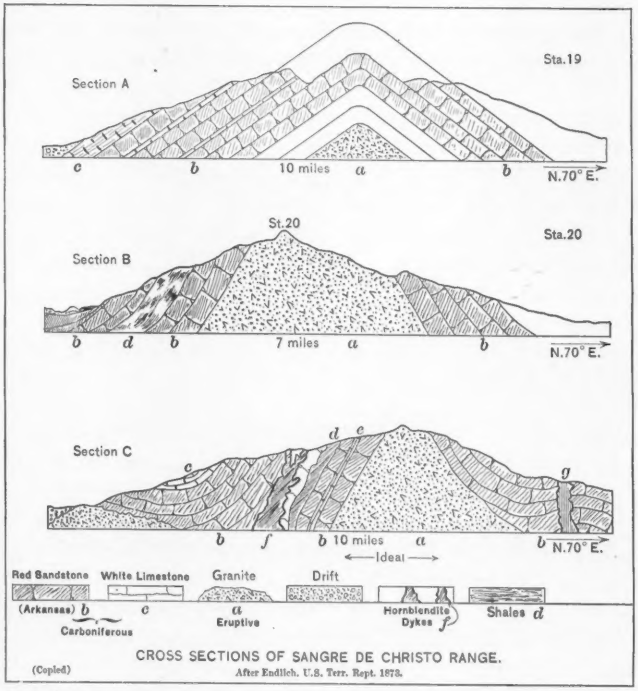

FIG. 65. Transverse Sections Across Sangre De Christo Range. Section A, near Rito Alto Peak; section B, usual section across the range; Section C, ideal section.

Although Mr. Endlich mentions the fact that granite everywhere forms the centre of the range and while I observed its outcrop to the north of the Rito Alto peak I could find no trace of the subjacent granite in riding to the summit of the mountain where one overlooks the San Luis valley to the west.

Near the crest of the range I found a few indefinite fragments of paleozoic fossils, crinoidal and brachiopod types, but they were too imperfect for identification.

AGE OF THE RANGE.

The backbone of the Sangre de Christo Range consists in its southern portion of metamorphic granite, in its central extension of a red feldspathic granite, and save the two intervals at Trinchera and Rita Alto peak the granite forms the crest of the uplift.

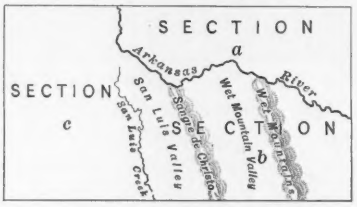

FIG. 66. Diagram Showing Location of Mr. Endlich's Section.

This granite has long been considered the youngest of the eruptive masses forming the Front Range group. Dr. Cross states:[1] "The granites and gneisses of the Rocky Mountains have always been considered to be a part of the Archean, the oldest known complex of rocks, whether deemed to be of plutonic eruptive, or of metamorphic origin." He then adds the important observation: "But a remarkable feature of the area of the Pike's Peak sheet, now observed for the first time, is the occurrence in the main granitic masses of an enormous number of intruded fragments of quartzite and of schists derived from them."

The granites of the Front Range have been shown to be of Algonkian or early Cambrian age. The granite of the north portion of the Sangre de Christo is covered by Silurian sediments as shown in the Wheeler and King Survey maps of Colorado and since the remaining area is only covered by Carboniferous strata resting directly upon the granite the region must have been

[1] Pikes Peak Folio, U. S. Geol. Survey, No. 7, p. 4.

a low-lying shore throughout early Palaozoic time while the Wet Mountain uplift farther east was an elongated island composed of an earlier granitic axis. Mr. S. F. Emmons discusses this at some length in his excellent paper entitled "Orographic Movements."[1] In the paragraph on the Wet Mountain and Sangre de Christo Islands (p. 272) he states that the two islands were consolidated into one land mass during Jurassic time. If any Triassic sediments had been deposited upon Carboniferous strata they were later eroded away.

The eastern shore line of this range resembled its present outline with a reëntrant bay in Huerfano Park which extended far up into the Wet Mountain Valley.

The Spanish Peaks lying far to the south by a little east do not properly belong to this uplift. Their origin is volcanic, they are laccolitic in character, and they were intruded as dikes, sills, and laccolitic masses into the overlying sediments. These represent the latest phase of volcanic energy attendant with the uplifting of this region, and which like the Cripple Creek volcanoes just north, belong to a very recent geologic epoch (Late Eocene and Early Miocene?).

The western portion of the Spanish Peaks is bordered by the Huerfano formation dipping westward. They rise to the northwest and dip in opposite direction conformable with the folds of the Sangre de Christo Range. The relation of these two areas is however more intimate than we would at first imagine, and as bearing upon this Prof. R. C. Hills[2] states: "A few miles west of the district there are extensive exposures of reddish brown coarse conglomerates, the Sangre de Christo Formation, which attains an enormous thickness and is regarded as of upper Carboniferous age." "It was the erosion of this conglomerate that furnished the bulk of the material composing the Huerfano beds of the Spanish Peak area." The Sangre de Christo formation is the "Arkansas Sandstone" of Mr. Endlich.

Referring to this period of uplift Mr. Hills writes: "It was this period of elevation and mountain growth that witnessed the

[1] *Bull. Amer. Geol. Soc. Amer.*, Vol. I., 1890, pp. 252–273.
[2] U. S. Geol. Survey, Spanish Peaks Folio, No. 71, p. 2.

initial stages of upheaval of the Sangre de Christo Range, west of the district. At about the same time the pre-existing Greenhorn mountains to the north were also uplifted, the strata of the plains border to the east were arched up, and a synclinical depression that was formed between this arch and the Greenhorn mountains on the one hand, and the Sangre de Christo Range on the other, became the basin of the Huerfano Eocene lake."

He continues on page 3: The uplifting of the Sangre de Christo Range was accompanied by the formation of a great flexure along the eastern base, a few miles west of the Spanish Peak district." "The diminishing slopes of this flexure extend a sufficient distance across the boundary to impart a decidedly eastern inclination to the strata along the western border south of the Spanish Peaks amounting in places to 20°."

This same author in the Walsenburg folio[1] adds: "The earliest eruptions of the Spanish Peaks took place after the close of the Bridger Eocene." The volcanic disturbances north of the area referred to by Mr. Hills are seen in the trachyte masses occupying limited areas close to the Sangre de Christo Range as at Hillside and in isolated patches in the southwest part of the range.

According to Mr. S. F. Emmons in his paper already mentioned, some twelve orographic movements were recognized by various authors prior to 1873 in the Rocky Mountain uplift. Mr. J. J. Stevenson appears to have been the first to point out the occurrence of four major upheavals in the central Rocky Mountain area. These were: (1) At the close of the Carboniferous (2) at the close of the Trias, (3) at the close of the Cretaceous, and (4) during early Tertiary time. The latest uplift of the Sangre de Christo Range in Tertiary time must have been comparatively rapid, but even much more rapid must have been the earlier elevation to have allowed the deposition in the Sangre de Christo Range of granite and gneissic boulders from Archean rocks, which in some instances according to Mr. Emmons are nearly fifty feet in diameter.

Near the base of the mountain of Rito Alto the Carboniferous sandstones are remarkably uniform in the size of their component

[1] U. S. Geol. Survey, Walsenburg Folio, No. 68, p. 2.

grains even through great thickness of rock strata. This is clearly shown in the various tunnels penetrating the sandstone of this mountain, two of which cut through nearly 1,000 feet of rock. Occasionally thin beds of shale or coarse conglomerate bands are interbedded, but the bulk of the main sandstone is a coarse reddish brown, siliceous sandstone, with rather massive bedding.

Where the sandstone is faulted and decomposed in this shear zone, mineralization is pronounced on the east slope of Rito Alto Peak and near the base of the mountain, and the Copper ores deposited there are being extensively prospected by long adit tunnels.

ORE DEPOSITS.

No important and permanent large mining camps have ever been developed in the Sangre de Christo Range proper. As early as the Hayden survey some mines in the southwest section were producing placer gold which had come from creeks heading into the Sangre de Christo mountains. Even the great laccolitic eruptions of the Spanish Peaks area do not appear to be largely mineralized, and, according to Mr. Hills,[1] the occurrence of ores containing precious metals is confined to West Spanish Peak.

Copper deposits of some importance are developed in the metamorphosed schistose granites about five miles north of Salida and within the past five years a number of copper properties have been under development at the base of Rito Alto mountain. Some of the workings here have exposed considerable chalcopyrite and siliceous ores (chrysocolla) which in course of development work have been shipped in small carload lots to the smelters. This ore averaged about 10 per cent. copper with a small content in silver and a trace of gold.

The chalcopyrite ore occurs in conjunction with fault planes in the Carboniferous sandstone, and along the bedding planes and joint fractures of the massive rock strata which have been folded into the anticline forming Rito Alto Peak.

The Salida deposits on the other hand have been developed in

[1] U. S. Geol. Survey, Spanish Peaks Folio, No. 71, p. 7.

connection with shearing movements and are due to metamorphic agencies acting through the granitic mass. In great lenses of micaceous gneiss, near the deposits, are developed remarkable garnet crystals of many pounds weight.

In Rito Alto mountain the ores are primarily due to faulting of the sandstone, faulting so pronounced that it has opened the way for the passage of mineral-bearing (copper sulphide) solutions which have deposited their contents along the fracture zones and adjacent joint planes which are present in the sandstone strata near the fault plane. One such fracture is clearly seen in the open workings at the outcrop of the mineralized belt above the Peerless Company's workings.

Since the purpose of this article is not to discuss the economic value of these deposits from a commercial standpoint we may pass directly to the theoretical consideration of their probable origin.

Copper in sandstone may be either original from contemporaneous deposition with its various strata or it may be introduced secondarily. The writer believes that in Rito Alto mountain the copper ores came from original granitic masses forming the Carboniferous islands of southern Colorado. These, after contributing a sufficient mass of sandstone material to form the Upper Carboniferous (Arkansas) sandstone of between four and five thousand feet in thickness were reburied, together with the granite of the Sangre de Christo Range, and except for Jurassic elevation and depression these rocks remained until early and middle Tertiary time before being elevated to form the present Sangre de Christo Range. Thus the ultimate source of the ore would be in the granite but the ore would also be original in the Carboniferous sandstone since it was deposited by sedimentary processes contemporaneously with it.

The percentage of copper impregnation in such sediment was, of course, very low, and the amount widely distributed throughout the formation, but it was thus ready for the concentration along fracture zones when the final Tertiary uplift occurred.

With this final elevation were developed the long northeast and southwest faults when the great anticlinal fold of Rito

Alto was formed. Along the fracture planes percolating subterranean mineral-bearing solutions, flowing chiefly down the slope by gravity but partly by hydrostatic pressure, acted upon the lower sedimentary layers and brought up to near the present surface the copper ores leached from the mass of sandstone strata now forming the Rito Alto mountain group. The fault planes were the limits of movement of these mineral-bearing solutions as they flowed downward from higher ground.

Such solutions would be most readily deposited where the frac-

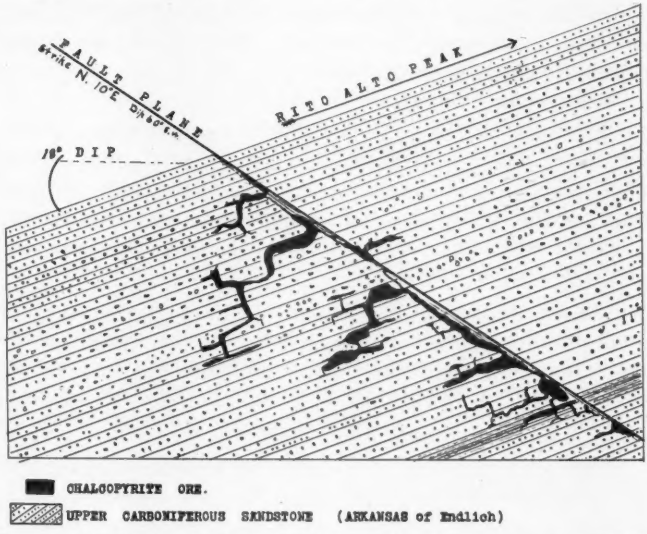

FIG. 67. Sketch Showing Ore Deposition Along Fault Planes in Sandstone in Rito Alto Mountain, Custer Co., Colorado.

ture zones had most intensely disturbed the stratification of the sandstone and this is where the ore is now found. The joint planes of the rock as much as thirty feet or more from these fault zones carry chalcopyrite seams which, however, are more pronounced in their development in the bedding planes of the sandstone at their junction with the fault plane.

That these water courses did exist is evidenced by such an opening as is seen in the lowest tunnel of the Rito Alto Company where an opening as large as a man's body extends back from the fault plane. This opening shows the customary water-worn surfaces of erosion, characteristic of the action of subterranean water. This opening appears to end blindly at the fault junction where a barite and quartz vein filling one foot wide and carrying considerable iron oxide, has been intersected by the tunnel extension into the mountain.

That the ore bodies are not larger is explained by the rigidity and insoluble character of the sandstone which did not allow large solution chambers to form after faulting as is so frequently found in limestone formations.

The ore is thus in its present position of secondary origin. Further drifting along these fault zones should develop additional ore. We have good reason to suppose that such ore deposition may be recurrent at various depths and therefore ore may be present in limited amounts at various levels below the present workings.

The following sketch showing the position of the ore, with reference to the fault lines and joint planes may, perhaps, make clearer the above statements.

SUMMARY.

Briefly stated, I believe that the copper ores observed on Rito Alto mountain were originally derived from subjacent cupriferous veins in granite and schist, the erosion of which from Carboniferous islands in southern Colorado formed the 5,000 feet of Carboniferous ("Arkansas") sandstone which sediments carried copper and iron in small amounts throughout their mass and which would thus be contemporaneously deposited with the sandstone strata.

This sandstone, during the Tertiary mountain-making movement of the Front Range, was elevated and thrown into the great anticline of Rito Alto mountain and coincident with such uplift were developed the north and south fault planes veering slightly

to the eastward. These fault planes made possible secondary ore deposition and enrichment along the fracture zones.

The ferruginous sands with their small and widely diffused copper contents furnished the ingredients necessary for both chalcopyrite and chrysocolla.

This theory is strengthened by the fact that there appears to be no eruptive rock anywhere near or beneath these ore bodies which could furnish the necessary minerals, while the porous nature of any sandstone, however massive it may be, when thrown into anticlinal folds would allow rapid percolation of mineral-bearing waters along its bedding planes as well as to a less extent through the sandstone itself. When we consider that these same sediments at the summit of the mountain are to-day about 4,000 feet above the known ore bodies and that the formation has a thickness of some 5,000 feet it becomes the more plausible to suppose that the ore came from above rather than to believe that it was derived by ascending solutions rising from great depths along the fracture planes.

Undoubtedly, water acting by gravity downward against these deformation lines would exert a hydrostatic pressure and some of the metallic contents would thus be carried up near the surface and be distributed along the disturbed zone. Had these sandstones been as soluble as ordinary limestone, the ore bodies probably would have occupied larger cavities and solution chambers, and they would have been of much greater extent.

These deposits are, therefore, of secondary origin as at present developed, and they mark the very latest phase of geologic action which took place subsequent to the Sangre de Christo Mountain uplift as it exists to-day.

EXPERIMENTS ON THE SEPARATION OF THE CONSTITUENTS OF A SOLUTION BY FILTRATION THROUGH A MINERAL FILTER.

EUGENE C. SULLIVAN.

The possibility that the rock-wall of a vein acts as a dialyzer, allowing some dissolved substances to penetrate it while confining other substances to the vein, was suggested by G. F. Becker.[1] Recently W. Lindgren and F. L. Ransome[2] have discussed the subject in detail in connection with Cripple Creek gold deposits. On the experimental side, F. H. King and later L. J. Briggs,[3] filtering very dilute soil solutions (containing potassium and sodium carbonates, sulphates, nitrates, and phosphates) through a porcelain tube, observed an increase in the concentration of the unfiltered portion and a decrease in the concentration of the filtrate. "This would follow from the tube behaving as an imperfect semi-permeable membrane, allowing the water to pass through the filter walls more readily than the dissolved salt."[4]

The work to be described in the present paper was carried out with an ordinary small Pasteur-Chamberland filter-tube enclosed in a stoppered glass cylinder to prevent evaporation. To wash the tube several liters of the ferric sulphate solution were passed through before observations were begun.

A solution of ferric sulphate of about $\frac{1}{1000}$ molecular concentration (Ca 0.562 g. $Fe_2(SO_4)_3$, $9H_2O$ in one liter) was filtered through the Pasteur tube under pressure of one or two feet of water. Oxide of iron began to separate owing to hydrolysis soon after the solution was made up and this substance formed an adherent coating on the filter and became in fact a

[1] "Mineral Resources U. S. for 1892," *U. S. Geol. Survey*, 1893, p. 156.

[2] "Geology and Gold Deposits of the Cripple Creek District, Colorado," Prof. Paper 54, *U. S. Geol. Survey*, pp. 228–231.

[3] *U. S. Dept. Agr., Bull. Bur. Soils*, No. 19, 1902, p. 36.

[4] For references to further work along related lines, see *Bull. 312, U. S. Geol. Survey*, pp. 7–10.

part of the filtering medium. The iron content of the filtrate was compared colorimetrically with that of a portion of the original solution filtered through paper to remove the ferric oxide precipitated as a result of hydrolysis. 5 c.c. of each solution were taken with 1 c.c. dilute HCl, 1 c.c. ½ normal KCNS, 10 c.c. H_2O; total 17 c.c. It was found that the solution not filtered through the Pasteur filter required more than 3 c.c. of water to reduce its color to that of the solution filtered through porcelain. The filtration had therefore caused a loss of about 18 per cent. of the iron.

A second lot of the ferric sulphate solution was similarly filtered through the Pasteur filter. After nearly all (about 2.5 liters) had passed through, a perfectly clear portion of the unfiltered solution which remained in contact with the filter was drawn off and compared colorimetrically for iron with a portion of the filterate. 5 c.c. of each solution were taken with 1 c.c. dilute HCl, 1 c.c. ½ normal KCNS, and 15 c.c. H_2O; total 22 c.c. The unfiltered solution required 3 c.c. to make the colors of the two solutions alike; hence 12 per cent of the iron originally present had been removed by filtration. In another experiment in which the original solution was filtered through paper for comparison with that filtered through the Pasteur filter, the loss of iron due to filtration through the Pasteur filter was about 18 per cent.

A third lot of ferric sulphate solution gave the following results on comparing the original solution with the first filtrate through the Pasteur filter:

5 c.c. of each solution were taken with 2 c.c. dilute HCl, 2 c.c. KCNS, 25 c.c. H_2O; total 34 c.c. The original solution required 7 c.c. of water to make the colors alike. The loss of iron had therefore been 17 per cent.

To make certain that the loss of iron was not due to the removal by the fine-grained filter of ferric oxide held in ordinary mechanical suspension as a result of precipitation by hydrolysis, the solution filtered once through the Pasteur tube was compared with solutions which had undergone repeated filtrations. Such a comparison, using a third lot of ferric sulphate solution, resulted as follows:

5 c.c. each of first and second filtrates were taken with 2 c.c. HCl, 2 c.c. KCNS, 20 c.c. H_2O; total 29 c.c. The first filtrate required 4 c.c. of water to reduce its color to that of the second filtrate. The second filtration had therefore removed 12 per cent. of the iron present in the first filtrate.

Another portion of the third lot of ferric sulphate solution was filtered four times through the Pasteur tube. Determinations of the iron in the original solution and in the fourth filtrate resulted as follows:

Original solution—

Found in 100 c.c. gravimetrically	0.0090 g.	Fe_2O_3, etc.
Found in 100 c.c. volumetrically	0.0093 g.	Fe_2O_3
Mean	0.0092 g.	Fe_2O_3

Fourth filtrate—

Found in 100 c.c. gravimetrically	0.0069 g.	Fe_2O_3, etc.
Found in 100 c.c. volumetrically	0.0065 g.	Fe_2O_3
Removed from 100 c.c. by filtration	0.0027 g.	Fe_2O_3
=	29 per cent.	

The original solution in this case became perfectly clear on standing and was compared directly with the fourth filtrate.

To determine whether the loss of iron was due to precipitation resulting from double decomposition between the ferric sulphate and the silicates of the Pasteur tube the filtrate from the ammonia precipitate in 500 c.c. of the fourth filtrate was evaporated, ammonium salts expelled, and the non-volatile residue weighed. The weight was 0.0084 gram, made up of sulphates of calcium, magnesium, and the alkalis. Counting the difference between the weight of the ammonia precipitate in 100 c.c. fourth filtrate (0.0069 g.) and the ferric oxide found by titration (0.0065 g.) as alumina, there would also be in 500 c.c. 0.0020 g. Al_2O_3.. The total substances other than iron in 500 c.c. fourth filtrate amounted therefore to between 0.22 and 0.26 milligram-equivalent, insufficient to have precipitated the 0.50 milligram-equivalent of ferric oxide which the solution had lost.

To ascertain the purity of the ferric sulphate used 1 g. was

dissolved in hydrochloric acid, the iron was precipitated with ammonia, the filtrate evaporated, and the non-volatile residue weighed. It amounted to 0.0012 g., which is equivalent to 0.0003 g. in 500 c.c. of the $\frac{1}{1000}$ molecular solution. The impurity is therefore negligible.

A fourth lot of ferric sulphate solution was subjected to four filtrations through the Pasteur tube. The first and fourth filtrates, lot 4, contained respectively in one liter:[1]

	Filtrate 1.	Filtrate 4.	
		Portion 1.	Portion 2.
SiO_2	not det.	0.0067	0.0068
Al_2O_3	0.0017	0.0052	0.0031
$CaSO_4$		0.0054	
$MgSO_4$ + alkali sulphate	0.0095		0.0115
		0.0065	
	0.0112	0.0171	0.0146
Fe_2O_3	0.0811	0.0655	0.0640

The losses of ferric oxide caused by the filtrations subsequent to the first were 0.0156 g. and 0.0171 g. respectively in the two portions, while the substances taken up by the solution in the course of the same filtrations weighed (0.0171 — 0.0112 =) 0.0059 g. and (0.0146 — 0.0112 =) 0.0034 g. respectively. The bases contained in the 0.0059 g. alumina and sulphates could have precipitated by double decomposition 0.0063 g. ferric oxide at most. The bases dissolved from the filter are therefore too small in quantity to account by double decomposition for the iron removed from the solution.

A fifth lot of ferric sulphate solution was made up and liter portions of the original solution, clarified by settling, and the first filtrates were analyzed, with the following results:

	Original Solution.	Filtrate 1.
SiO_2		0.0068
Al_2O_3		0.0036
$CaSO_4$		0.0035
$MgSO_4$ + alkali sulphates		0.0083
Sum, Al_2O_3 + sulphates		0.0155
Fe_2O_3	0.0901	0.0589

[1] It is needless to say that the analyses were carried out in platinum dishes, with careful checks on the purity of the reagents used.

The loss of ferric oxide is 0.0312 g. per liter, about 35 per cent. of that originally present. The bases taken into solution could have precipitated only about 0.010 g. Fe_2O_3. The original solution taken for analysis was absolutely clear to the eye, and the unused portion stood for a month longer without giving the slightest indication of turbidity.

The following comparisons of the SO_4 content of the solutions before and after filtration show that the concentration of the acid radical remains unchanged in spite of the heavy loss of iron. The iron is, therefore, not precipitated as basic sulphate, and inasmuch as the other bases found in the solution are not equivalent to the iron removed, it follows that the filtration has rendered the solution acid.

EFFECT OF FILTRATION ON SO_4 CONTENT OF FERRIC SULPHATE SOLUTION.

Lot No.	Solutions Compared.	Grams $BaSO_4$ from 100 c.c.		Loss of Iron. Per Cent.
		Before Filtration.	After Filtration.	
2	Original and First Filtrate.	0.0421[1]	0.0411[1]	12
3	Original and First Filtrate.	0.0778	0.0788	17
3	Original and Fourth Filtrate.	0.0778	0.0773	29
5	Original and First Filtrate.	0.0782	0.0791	34

DISCUSSION.

A salt in passing in solution through a porous mass similar in character to the wall-rock of a vein may undergo separation, then, to a certain extent into its constituents. In seeking for the cause of this differential permeability we have first the fact that the solution takes up bases in its passage through the filter, which would indicate that some double decomposition with the silicates of the filter has taken place, resulting in precipitation of the ferric oxide. Silicates in contact with salt solutions are known to enter immediately into chemical reactions of this nature.[2]

A second cause of separation not less important lies in the fact that the iron of the ferric sulphate solution is present largely as colloid oxide. Water decomposes (hydrolyzes) the salts of weak acids or bases, and the base usually remains dissolved as a colloid:

$$Fe_2(SO_4) + 3H_2O = Fe_2O_3 + H_2SO_4.$$

[1] From 50 c.c.

[2] See *Bull. 312, U. S. Geol. Survey.*

Now such a colloid solution appears to be at best a very fine state of suspension[1] and it is to be expected that a close-grained filtering medium such as the Pasteur tube, and especially the colloid ferric oxide deposited on its surface, would remove a part of this fine suspended material. It is well known that colloids are impermeable to colloids, although permitting other dissolved substances to pass through them freely.

The proportion of base in the colloid condition in a solution of its salt is greater the greater the dilution, the weaker the base, and the weaker the acid. Potassium, sodium, and the other alkali metals, and barium, strontium, and calcium from strong bases whose salts are scarcely decomposed by hydrolysis, while at the other extreme are the heavy metals, whose salts in solution are broken up to such an extent that a large part of the base and acid are present in the free state, the base in colloid solution. Filtration of the kind described would tend to separate the strong from the weak bases.

Another possible factor in producing the phenomena under discussion is the different rate of diffusion of the constituents of a solution. Where a rock wall is impregnated with ferric sulphate solution on one side and comparatively pure water or a solution of another salt on the other side, movement of the salts will take place by diffusion. The colloid ferric oxide of ferric sulphate solution moves very slowly as compared with the sulphuric acid; Graham's[2] experiments showed that colloids diffuse about one fiftieth as rapidly as acids.[3]

We are in a position, then, to form a fairly clear idea of the process by which separation of the constituents of a solution takes place in contact with a vein-wall, some passing into the rock and penetrating it for indefinite distances while others remain in the vein and are carried away in solution or deposited on or near the surface of the rock-wall.

[1] See, for instance, A. A. Noyes, *Jour. Am. Chem. Soc.*, 27, 95–97, 1905.

[2] *Liebig's Ann.*, 121, 1, 1862, cited by Ostwald, Lehrb., 1, 702.

[3] The fact that the power of the filter to remove iron does not decrease as filtration proceeds appears effectually to preclude in this case the calling in of "adsorption" to do duty in accounting for the loss of material from solution.

Taking as an example a solution of ferric sulphate, a product of the oxidation of pyrite, it will enter into chemical reaction with the silicates of a rock-wall, a partial exchange of bases resulting, and both colloid silica and colloid ferric oxide probably will be deposited as solids.

To penetrate the rock further the solution must now make its way through the colloid oxides[1] as well as through the interstices between the particles which make up the rock.[2] Both these filtering media tend to strain out the colloid ferric oxide of the solution, while the sulphuric acid finds more ready passage. The iron oxide thus accumulates at or near the surface of the rock-wall, while the acid passing through attacks the rock and is eventually neutralized by the bases of the silicates, giving rise to sulphates of sodium, potassium, calcium, etc. The total result is a metal-bearing vein enclosed by decomposed rock.

The oxide deposited in this manner will easily be changed to sulphide or to other forms under suitable conditions, or the sulphide itself may be in colloid solution originally and be filtered out by the fine-grained rock aided by films of colloid material.

To summarize, it has been shown experimentally: (1) That a porous silicate filtering medium similar in character to a vein-wall removes iron from ferric sulphate solution, and (2) does not remove the acid radical; (3) that the solution takes up bases from the filter; and (4) that these bases are insufficient in quantity to have removed the iron by double decomposition.

The ferric oxide appears therefore to have been filtered out in a state of colloid suspension by the fine-pored silicate mass aided by films of colloid ferric oxide and silica.

This work was done in the chemical laboratory of the U. S. Geological Survey.

[1]See Lindgren and Ransome, *l. c.*

[2]S. L. Bigelow has directed attention to the essential similarity of movement through capillary spaces and through colloid membranes. *Jour. Am. Chem. Soc.*, 29, 1675–92, 1907.

REVIEWS

Fossil Iron Ores of Georgia. By S. W. McCallie, State Geologist. Geological Survey of Georgia, Bulletin No. 17. Pp. 199, Pl. 14, Maps 3. Atlanta, 1908.

Of the sixteen chapters in this publication one is devoted to the general distribution of the fossil ores in the United States, one to the rocks associated with these ores, two to the general geology of the region of these ores in Georgia, five to detailed descriptions of the various iron-ore properties in the state, one chapter each to the megascopic characteristics, the microscopic characteristics and the chemical composition of the ores, and three chapters to a discussion of their origin.

In connection with the description of the ores there is a map of the eastern United States indicating the general geographical distribution. It is interesting to note that this map, which is in general correct, shows few localities not noted by J. P. Lesley in his description of these ores published in 1859. Lesley mentions a few unimportant localities not given by this author. There is comparatively little recently published information to compile from. During the middle of the last century, coincident with the development of the use of anthracite coal as a blast furnace fuel, these ores were extensively mined in New York and Pennsylvania and some attention was given to them by the geological surveys of these states. In recent years their relative importance has markedly decreased except in the southern Appalacian states and correspondingly less attention has been given to them by geologists. The meagerness of published information and the evident lack of first hand information has led to some misleading statements in regard to general distribution and the continuity of the outcrop. In Virginia the ores have not been as widely mined as stated nor is the outcrop of the ores as persistent and continuous as is claimed.

The fossil ores of Georgia are shown to be confined largely to four of the northwestern counties of the state. The Rockwood formation in which the ores occur is about 500 feet thick in the western part of the region and 1,500 feet in the eastern part, and consists chiefly of shales with thin beds of limestone, sandstone and iron ore. The ores occur chiefly about 200 feet below the base of the Devonian shale or

the top of the Rockwood formation. There are usually present at any given place several beds of iron ore separated by a few inches or a few feet of other strata. The beds are commonly a few inches thick with a maximum of about three feet. The strata are lying in gentle folds with dips of 10 to 30 degrees. The ores generally outcrop on the lower slopes of the valleys along the eroded limbs of the folds but less often on the tops of anticlinal or synclinal mountains. Throughout the outcrop of the formation the ores are practically continuous. It is estimated that in the ore region of this state there is a total length of outcrop of the ores of 175 miles. The greater part of this is workable.

Some of these ores are worked to a depth of a couple of hundred feet but for the most part they are mined to a depth of a few feet only along the outcrop.

There was little development of the ores before the civil war. During and after the war they were mined for a number of charcoal furnaces. In recent years they have been mined for one local modern furnace and for shipment to points as far north as southern Virginia.

Forty-six analyses are given. These are unusually complete and include determinations of ferrous iron and carbon dioxide. The average iron content of the weathered or "soft" ores is about 52 per cent. while that of the unweathered or "hard" ores is about 40 per cent. The value of these analyses would have been greater if the mode of sampling had been described.

From the time of the early state surveys to the present there has been considerable discussion as to whether these ores are original bedded deposits or are secondary concentrations. The author gives the views of the leading writers on the subject and in the final chapter gives his own theory of the most probable origin of the Clinton ores. He says: "These ores are in a large measure only altered beds of glauconite." He states that the evidence which is found in "The geological conditions, the nature and character of the associated rocks, the microscopic study and the chemical composition of the ores," is not conclusive but strongly supports the theory. He describes the conditions prevailing at the time of the deposition of the Clinton sediments as similar to those now prevailing along the Atlantic coast where glauconite is now forming. The evidence, which he derives from his own microscopic study, in which he finds green nuclei to some of the iron granules, which green material he concludes to be glauconite, he supports by similar studies by Dr. C. H. Smythe, and by Dr. C. K. Leith on Mesabi ores, quoting from the latter writer. The microscopic study of glauconite by Ehrenberg is used to show the similarity of glauconite and the fossil ores. The analyses show ferrous iron to be present in all cases and in the unweathered ores this constitutes 4 per cent. of the total iron present. The quantity of carbon dioxide present indicates that the ferrous iron

is present as silicate. The fact that 96 per cent. of the iron is in the ferric condition under the surface of the ground water is explained by assuming that the glauconite beds were the most porous layers in their immediate horizon and therefore were the trunk channels of water circulation after erosion had cut these beds on folds and surface waters carrying carbon dioxide and oxygen could readily change the glauconite beds to the condition now found by solution, transportation and oxidation. To supply the deficiency of iron in glauconite, which is less ferruginous than the fossil ore, he suggests the possibility of concentration in the ore beds from ferrous sulphate and carbonate in adjoining strata.

The presence in certain deep-seated situations of large percentages of ferrous iron may be a significant discovery. Confirmation of this in other regions will be awaited with interest. So much ferrous iron is surprising when it is remembered that the quantity heretofore known in these deposits has been insignificant and that ore from workings down 2,000 feet on the slope in the Birmingham region appears to be as fully oxidized as that from immediately below the base of the belt of weathering. Aside from its purely geologic interest this discovery suggests that prospect drilling may have cut the ore strata at points which are high in ferrous iron and the material not have been recognized as the ore equivalent.

This theory of the origin of the fossil ores is a new contribution and merits consideration. The presence of much ferrous silicate is not readily explained by previous theories. Many years ago glauconite was considered as the source of the New Jersey bog ores and more recently of certain surface ores in Texas.

While it is not the purpose of the reviewer to criticise this theory at this time, the following suggestions are offered, in the hope that others will contribute observations bearing on the question.

The gradation to unaltered glauconite is not established. The gradation through several miles from ferric to ferrous iron is not in accordance with usual transitions of this kind, which are abrupt. The strata associated with the fossil ores are not favorable to the theory of secondary enrichment of the ore bed from adjacent strata. Such strata are usually shale and commonly have considerable dip, which attitude is not favorable to joint planes. In Kentucky the fossil ores have iron carbonate interbedded with the normal fossil ore. R. J. HOLDEN.

Lead and Zinc in the United States. By WALTER RENTON INGALLS. 368 pp. with illustrations. Hill Publishing Co., New York, 1908. Price $4.00.

The title of this book is a broad one but the real scope of the work is explained by the subtitle which reads "An Economic History of the

Mining and Smelting of the Metals and the Conditions Which Have Affected the Development of the Industries." The preface affords the intresting information that the work was prepared at the request of the Carnegie Institution and is to form a part of an "Economic History of the United States" to be published by that organization. The present volume speaks well for the success of the undertaking.

Mr. Ingalls's book is divided into two parts, about two thirds being devoted to lead and the remaining third to zinc. It may be said at the outset that the geology of the deposits is touched on only incidentally but there are books dealing with the border lands of his science which the economic geologist cannot afford to overlook. Of such the present volume is a happy example.

The first chapter describes the occurrences of lead ore and the geological reader will doubtless regret its brevity and lack of references to the best and latest literature on the various districts mentioned. For example, in his account of the Wood River district of Idaho, consisting of four lines, Mr. Ingalls gives one reference to Kemp's "Ore Deposits," and does not cite Lindgren's important work on that region. The statement (p. 17) that the gangue of the Cœur d' Alene ores is quartz needs substantial modification. In most of the larger mines siderite forms a much larger part of the gangue than does quartz.

Chapter II. is a useful chronology of the principal events in the history of lead mining.

The third chapter on the metallurgy of lead is an excellent and clearly written resumé of a field that is Mr. Ingalls's own. The various processes are described and the history of their trials and adoptions related in language that is easily understood, even by one who is not a trained metallurgist. The progress of silver-lead smelting is traced from its infancy at Eureka, Nevada, to the high state of the art as practiced in the modern American smelters.

The fourth chapter deals briefly with the refining, marketing and uses of lead.

Chapters V. to XII. are devoted to the history of lead mining in (1) the Eastern and Southern States, (2) Missouri, (3) Wisconsin (including parts of Illinois and Iowa), (4) Arizona and New Mexico, (5) Colorado, (6) Idaho and Montana, (7) Nevada and Utah.

Statistics of production, consumption and prices are succinctly treated in Chapter XIII.

Under "Commercial Conditions" which forms the heading of Chapter XIV., Mr. Ingalls recognizes fully the beneficial results of the application of geological knowledge to the discovery and development of deposits of lead ores. Citing the classic work of Emmons at Leadville and testifying personally to the esteem in which it was held in early days in that district, he says that "this work alone is sufficient

justification of the existence of the United States Geological Survey." After the advance in geological science as a factor in the lead production in the United States, Mr. Ingalls treats of the improvements in railway transportation and in reduction processes. On the whole he concludes that these have been more important than improvements in mining.

Chapter XV. discusses the Tariff on Lead and expresses the spirit of dissatisfaction with existing conditions that is slowly gaining ground. When the author speaks of "the pettiness that has animated the wire-pulling since the tariff became a means of filling the pockets of special interests" he pithily expresses what many of his readers must feel.

The following chapter on Labor Conditions also deals frankly with recognized evils in our industrial fabric. Mr. Ingalls points out with truth that mining in the West has suffered under the compulsion of paying higher wages than conditions justify, the concomitant of such high wages on the part of the recipients being not thrift but reckless waste, as shown by the saloons, gambling houses and brothels that flourish on the miners' wages. The high net earnings of the western miner are in most cases dissipated in folly, leaving him really worse off than his poorer paid but more frugal brother in the eastern states. Few who know the mining camps of the Rocky Mountains will be likely to question the pernicious effect upon the mining industry throughout that vast region of what Mr. Ingalls terms "the worst labor union that the United States has known."

Chapter XVII., on trade agreements and combinations, is concerned chiefly with the rise to power of the American Smelting and Refining Company, and with a discussion of the conditions which have rendered its dominance of the lead industry possible.

The part of the work dealing with zinc is, as Mr. Ingalls points out in the introduction, less interesting than that relating to lead inasmuch as the development of the zinc industry is modern and its history lacks those incidents that have colored with romance the exploitation of our lead deposits. The brief introduction is followed by chapters on (1) The Occurrence of Zinc Ores in the United States, (2) Zinc Mining, (3) Ore Dressing, (4) Zinc Smelting and (5) Commercial Conditions. A good index closes the volume.

The book contains very few minor or typographical errors and shows careful and accurate preparation. The writer's style, while occasionally showing such lapses as the use of what has been termed the "reporters' aorist" (pages 13 and 16) and a preference for unusual words where a familiar one would be more appropriate (on page 175, for instance, prospectors are said to have been looking for ores that could be "beneficiated" by amalgamation) is clear and to the point. The work can be heartily commended not only for its accuracy and

balance but also for its general interest and readableness. The publishers' share in the volume is also creditable, the book being well printed on good paper and appropriately bound.

F. L. RANSOME.

Fourth Biennial Report North Dakota Geological Survey 1905–1906. A. G. LEONARD, Ph.D., State Geologist. Pp. 324 with 37 plates and map.

One of the best recent treatments of the clay resources of a state is presented in this volume under the joint authorship of A. G. Leonard, C. H. Clapp and E. J. Babcock. The report deals with the properties of clay in general, the geology of North Dakota clays, tests of their chemical and physical properties, their uses and value, methods of brick manufacture and a description of the North Dakota brick industry.

Most of the geological formations of North Dakota contain clays of economic value and there is no large area in which no clays occur which are not suited at least to the manufacture of low-grade wares The lowest outcropping rocks are the Benton shales which are exposed only on the Pembina and Little Pembina rivers. The Niobrara is little more extensive, but the Pierre shale occurs throughout the central and eastern portions of the state. The Laramie and Fort Union formations while probably distinct have not been separated in North Dakota and in this report both are classed as Laramie. Those formations occupy the western half of the state. Pleistocene deposits, however, mantle the older rocks nearly everywhere.

The clays of the Benton, where tested, were suited to the manufacture of dry-pressed, red, front brick. The Niobrara clays are too calcareous to be of value but the Pierre shale while equally useless at the bottom is better at the top and can be used for making good red brick. The majority of the Laramie clays are too sandy to be used while the plastic clays have a very high air shrinkage and low fusibility. A striking feature of the Laramie formation is the beds of fused clay that have resulted from the burning of beds of lignite adjacent to the clay beds.

In the Tertiary above the Laramie, beds of white clay occur in a belt 50 miles wide and 90 miles long. The belt extends from Hebron on the east to Belfield on the west and extends about twice as far north of the Northern Pacific railroad as south. The plastic clays of these beds are 10 to 20 feet thick and the sandy clays 30 to 50 feet. The clays burn white, gray and buff. The clays are refractory and some of them have a range of five cones between incipient fusion and vitrification. Chemical analyses and laboratory tests of selected samples of the clays indicate that in their natural state they compare favorably

with clay used in eastern potteries. In commercial plants samples of the clays have been manufactured successfully into table ware, art pottery, enamel brick and glazed tile. The localities in which the clays occur are limited to the southwestern portion of the state and, although at present at considerable distance from any large pottery center, with the growth of population they should become the basis of a profitable industry.

The Pleistocene clays afford abundant material for the manufacture of common brick and tile. These clays, however, seldom burn red, so that practically all the common bricks of North Dakota are buff or pink.

EDWIN F. LINES.

URBANA, ILL.

RECENT LITERATURE ON ECONOMIC GEOLOGY.

G. F. LOUGHLIN and C. H. CLAPP.

METALLIFEROUS DEPOSITS.

ALUMINUM.

La latérisation et ses relations avec la genèse de quelques minérais d'aluminium et de fer et de certains gites aurifères. By J. CHAUTARD in collaboration with P. LEMOINE. Comptes Rendus Mens Ind. Min. April, 1908, pp. 119–125. (Abstract in Geol. Zentralb., Bd. XI., No. 11, p. 488, 1908.)

Comparison of laterite and argillaceous decomposition. Former limited to tropical climate. Origin of bauxites, including those of Arkansas, attributed to laterization. Superficial deposits of iron in tropical regions attributed to same mode of origin. L.

COPPER.

Foothill Copper Belt of the Sierra Nevada. Further discussion by S. W. BENJAMIN of paper by J. A. REID. Min. and Sci. Press. Vol. XCVII., No. 15, p. 490, 1908.

Calls for discussion of economic conditions rather than of minor points in mineralogy. Suggests that partially decomposed blende may have been mistaken for chalcocite. L.

Nacozari Mining District, Sonora, Mexico. By E. E. RUSSELL. Eng. and Ming. Jl. Vol. 86, No. 14, pp. 657–662, 1908.

Location and historical notes; brief description of extent and working of orebodies; quotation of Emmon's conclusions as to origin of ore; details of the several properties. L.

IRON.

Amarilla Iron and Phosphate Deposits. By O. H. HERSHEY. Min. and Sci. Press. Vol. XCVII., No. 16, pp. 535–536, 1908.

Gives location, describes character of ore bodies and states conclusions as to origin. L.

A New Theory of the Genesis of Brown Hematite Ores; and a New Source of Sulphur Supply. By H. M. CHANCE. Trans. A. I. M. E. Bi.-Mo. Bull. No. 23, pp. 791–808, 1908.

Briefly reviews and dismisses other existing theories regarding genesis of the limonite deposits in the Cambrian sandstones and slates bordering the Great Valley; presents evidence for believing that the limonite is a gossan residual after lenticular masses of granular pyrite; regards pyrite as a primary constituent, deposited either mechanically or by precipitation with the sand or mud of which the country rock was composed. Conditions of oxidation discussed. The theory is also believed to account for the limonites in the Oriskany, in the limestone areas of the Great Valley, and perhaps in other formations. Suggests that the underlying unoxidized pyrite bodies be prospected. L.

Report on the Fossil Iron Ores of Georgia. By S. W. MCCALLIE. Geol. Surv. of Georgia. Bull. No. 17, pp. 199. Atlanta, Ga., 1908.

Discusses origin of the Clinton fossil ore and data upon which to estimate the iron ore reserves. Considers the iron to have been derived from glauconite. L.

GOLD.

Deep Lead Mining in Australia. By D. H. BROWNE. Min. and Sci. Press. Vol. XCVII., No. 17, pp. 565–569.

Describes form and character of deposits and methods of overcoming serious difficulties. Editorial on p. 544 of same number makes interesting comparisons with the placers in California and Alaska that are worked underground. L.

Gold Mining at Waverley, N. S., Fifty-two Years Ago. Can. Min. Jour. Oct. 15, 1908, pp. 533–534, with a map. Compiled from notes made by J. W. DAWSON in 1866. C.

Gold Mining at Coromandel. By COLIN FRASER, assisted by J. H. ADAMS. New Zeal. Mines Rec. Vol. XL., pp. 194–197, 252–258, 292–297, 341–344, 381–384. From Bull. No. 4 (New Series), New Zeal. Geol. Surv. Wellington, 1908.

Detailed description of veins and claims. Summary of ore genesis and future prospects. C.

La Grange Hydraulic Mine (Trinity Co., Cal.). By D. F. CAMPBELL. Min. and Sci. Press. Vol. XCVII., No. 15, pp. 491–493.

One paragraph devoted to geology. Remainder to methods of working. L.

Report on a Portion of Conrad and Whitehorse Mining Districts, Yukon. By D. D. CAIRNES. Canada Geol. Surv. Report No. 982. Pp. 38, with colored map, 1908.

Describes topography, mining properties, and general geology. L.

Report of a Recent Discovery of Gold near Lake Megantic, Quebec. By J. A. DRESSER. Canada Geol. Surv. Report No. 1028, pp. 13, with colored map, 1908.

Outlines geology, occurrence, source and extent of gold, and advice on prospecting. L.

The San Juan Region, Colorado.—I. By T. T. READ. Min. and Sci. Press. Vol. XCVII., No. 19, pp. 632–635, 1908.

Notes the latest phases of development, including so much of the old as is necessary for complete discussion. A popular review rather than a scientific description. Includes a summary account of local geology. L.

LEAD AND ZINC.

Miami Lead and Zinc District in Oklahoma. By O. RUHL. Eng. and Min. Jl. Vol. 86, No. 19, pp. 910–912, 1908.

Brief description of ore occurrence and of difficulties of milling in this recently developed addition to the Missouri-Kansas zinc-field. L.

RARE METALS.

The Rare Metals. By C. BASKERVILLE. I. Beryllium. Eng. and Min. Jl. Vol. 86, No. 19, p. 907, 1908. II. Columbium. Eng. and Min. Jl. Vol. 86, No. 20, p. 960, 1908.

Gives lists of minerals containing these elements and the properties of the more important ones. (Intended especially for the benefit of prospectors.) L.

SILVER.

The Cobalt-Nickel Arsenides and Silver Deposits of Temiskaming. (Third Edition.) By W. G. MILLER. Ontario Bureau of Mines. Vol. XVI., Part II., pp. xvi + 212 with maps and illustrations.

Contains no fundamental differences in descriptions from the second edition, save possibly of the ores associated with aplite in the Montreal River area. Author's opinions practically unchanged. C.

Hinds Consolidated Mines, Mexico. By S. F. SHAW. Min. and Sci. Press. Vol. XCVII., No. 18, p. 598, 1908.

Mentions character of vein and ore in the different levels, but says nothing of local geology. Describes methods of working. L.

The Geology and Ore Deposits of the Cœur d'Alene District, Idaho. By F. L. RANSOME and F. C. CALKINS. Prof. Paper, No. 62, U. S. G. S. Pp. 203, illustrated. Washington, 1908. L.

Guanajuato, the Great Silver Camp of Mexico. By C. T. RICE. Eng. and Min. Jl. Vol. 86, No. 14, pp. 669–672, 1908.

General description of district, including abstract of current geologic knowledge (one column) and descriptions of ore zones and ore (two columns). L.

The Silver-Lead-Zinc Mines at Broken Hill (New South Wales). By G. W. WILLIAMS. Eng. and Min. Jl. Vol. 86, No. 17, pp. 793–801, 1908.

Extent of the lode and depth of oxidation in the several mines stated on first page; remainder devoted to methods of mining and illustrations. L.

The Silver Mines of Mexico. By A. F. J. BORDEAU. Trans. A. I. M. E. Bi-Mo. Bull. No. 23, pp. 629–640, 1908.

An up-to-date summary of the character and present condition of the silver mines of Mexico. The several districts are grouped into three classes: (1) Veins and stockworks in eruptive rocks; (2) fissure veins in schists and eruptive rocks; (3) veins and replacements in limestone. L.

The Silver Veins of the Montreal River District, Canada. By A. E. BARLOW. Min. and Sci. Press. Vol. XCVII., No. 14, pp. 462–465, 1908. (Abstract of paper in Bull. Can. Inst., July, 1908.)

Describes veins and country rock (quartz-diabase). Veins, attributed to pegmatitic origin, grade in composition of gangue from acid plagioclase, through a plagioclase-quartz mixture to an extreme of calcite and quartz. The ore minerals are described and similarity of this district to the Cobalt district is shown. L.

The Working Mines of Guanajuato. By C. T. RICE. Eng. and Min. Jl. Vol. 86, No. 17, pp. 806–808, 1908.

Brief descriptions of ore occurrence and workings of the principal mines. L.

NON-METALLIC DEPOSITS.

ASPHALT.

Die Asphaltindustrie. By F. LINDENBERG and A. HARTLEBEN. Wien. Pp. 320. Price 6 marks. Outline in Geol. Zentralb., Bd. 11, No. 11, p. 486, 1908.

Treats of the properties of natural and artificial asphalt and their applications. 34 pages devoted to natural asphalt. L.

CEMENT.

The Lime and Cement Resources of Missouri. By H. A. BUEHLER, Assistant State Geologist. Vol. VI., Second Series, Missouri Bureau of Geology and Mines. Pp. 205, illustrated. Jefferson City, Mo.

Brief description of raw materials used; uses and properties of the materials and methods of manufacture; description by counties of

geological position, occurrence, and extent of deposits; table of analyses. L.

COAL.

Coal. By JAMES TONGE. Pp. 275; illustrated, 5½ x 8½ in.; cloth $2. New York, 1907; D. van Nostrand Company.

A general treatise including history, occurrence, mode of formation, fossils in coal measures, botany of coal measure plants, coalfields of British Isles, foreign coalfields, classification, valuation, uses, production of heat from coal, waste of coal, preparation for market, and coaling stations of the world. L.

The Geology of Coal and Coal Mining. By WALCOT GIBSON. Pp. 341; illustrated. 5 x 7½ in. cloth, $2.50; New York, 1908; Longmans, Greene & Company. London: Edward Arnold.

Contents: varieties—chemical and physical characters. Coal as a rock. Formation and origin. Distribution. Fossils as zonal indices. Prospecting and boring. Study of an exposed coalfield. Study of a concealed coalfield. Coalfields of Great Britain, Southern Province. Coalfields of Great Britain, Midland Province. Coalfields of Great Britain, Northern Province, including Ireland. Coalfields of Continental Europe. North American coalfields. Coalfields of Africa, India, Australia, and South America. Coalfields of China, Central Asia, Japan, New Zealand and Dutch East Indies. L.

Jahrbuch der deutschen Braunkohlen-Steinkohlen- und Kaliindustrie. (Outline in Geol. Zentralb. Bd. 11, No. 11, p. 485, 1908.) By B. BAAK. VIII. Jahrgang. unter Mitwirkung des deutschen Braunkohlenindustrievereins, W. Knapp, Halle, a. S., 8°, 1908. Pp. 257 + 184 + 38. Price 6 marks. L.

Kohlenbergbau in Niederösterreich. By F. BLASCHKE. Mitt. d. Sekt. f. Naturk. d. österr. Touristenklubs, XX., Hg. (1908), pp. 17–21. Abstract in Geol. Zentralb., Bd. 11, No. 11, p. 485, 1908.

The different coal and lignite occurrences of lower Austria are grouped together and briefly described. L.

The Lignite Beds of Central Otago. By JAMES PARK. New Zeal. Mines Record. XI., 305–307.

From Bull. No. 2 (New Series), New Zeal. Geol. Surv. Wellington, 1908.

Description of occurrences of lignite and geology of the region, with analyses and tests of the lignite. C.

Map of West Virginia, Showing Coal, Oil, Gas, and Limestone Areas. By I. C. WHITE, State Geologist. 39 x 45 in.; paper 50 cents. Morgantown, W. Va., 1908. West Virginia Geological Survey.

Scale 7 miles to inch. Shows topography, coal and limestone areas,

principal anticlinal lines and developed oilfields and gasfields, and location, name, and address of every shipping coal company in state.

L.

The South Wales Coal-Field. Sections and Notes. By H. K. JORDAN. Proc. South Wales Inst. of Eng. Vol. XXVI., No. 1, Part 1. Cardiff, Sept. 30, 1908. Pp. iv + 84. III. Plates.

Detailed descriptions of sections, correlation of seams, and discussion of the origin of anthracite, with a summary of the writer's views:

1. "That the mineral impurities in the original bituminous coal of South Wales inhibited, in part, the elimination of the volatile constituents."

2. "That these impurities were deposited from streams of turbid water, or were filtered out by the vegetation as the coal seams were being formed, the turbidity being less in the anthracite regions."

3. "That the great differences of quality which occur . . . indicate that coal was derived from different species, or even from distinct genera, or plants."

4. "That heat and pressure were important factors in the anthracitisation, that the heat originated in the seams by the reason of the decomposition of the vegetation, and the gases given off, having no escape, set up pressure, and therefore heat also, and the elastic forces thus brought into play greatly increased the pressure and heat due to the weight of the superincumbent strata, each seam being thus more affected than the one above, and from this greater pressure and heat the greater density and other distinctive characters of anthracite have resulted.

C.

Supplementary Coal Report, West Virginia Geological Survey, Vol. II. (A). By I. C. WHITE, State Geologist. Pp. 720, with map and illustrations. Price $2. Morgantown, W. Va., 1908. West Virginia Geol. Survey.

A companion volume to Vol. II. Deals mainly with Great Kanawha and New River Regions and coalfields between these districts and the Kentucky line. Accompanied by coal analyses.

L.

PETROLEUM.

Das Erdöl, seine Verarbeitung und Verwendung. Eine gedrängte Schilderung des Gesamtgebietes der Erdölindustrie. By R. KISSLING. Halle a. S., W. Knapp; 8°. Pp. 154, with 30 text figures, 1908. Price 5.40 marks.

Abstract in Geol. Zentralb., Bd. 11, No. 11, p. 486, 1908.

First 48 pages treat of the composition, the geographic and geologic extent, mining methods, chemical and physical properties. Remainder of book considers the technical side of the subject.

L.

Regelmässigkeiten in der Lagerung des Erdöls. By H. STREMME. Petroleum, III. Jg., No. 17, Berlin, 1908.

Presents theory to account for the occurrence of heavier oils over lighter oils in some regions and the opposite relation in other regions. L.

Über die Entstehung der elsässischen Erdöllager. By L. VAN WERVEKE. Mitt. de Geol. L.—A. von Elsass-Lothr., Bd. VI., 1908, H. 1, pp. 1–30, with 3 figures. (Abstract in Geol. Zentralb., Bd. XI., No. 12, p. 539, 1908.)

Author differs from other writers and gives evidence to prove that the oil is original in its present position and not derived from greater depth. L.

STONE.

Quality of Bluestone in the Vicinity of the Ashokan Dam (N. Y.). By C. P. BERKEY. School of Mines Quarterly. Vol. XXIX., No. 2, pp. 149–158, 1908.

Part I., Geology; outlines physiographic and structural features, stratigraphy and general economic features, and gives the characters and conditions most desired for the particular use proposed, with recommedations as to the most suitable quarries.

Part II., Petrography; general description, emphasizing characters of special importance, with conclusion that no better stone need be desired for the proposed use. L.

TALC.

Talc and Soapstone in Vermont. By G. H. PERKINS. Eng. and Min. Jl. Vol. 86, No. 16, p. 753, 1908.

A brief account of location and extent of several beds, with one paragraph on production. L.

TOPAZ.

Topaz-Bearing Rhyolite of the Thomas Range, Utah. By H. B. PATTON. Bull. Geol. Soc. of Am. Vol. 19, pp. 177–192, pls. 12–13; July 23, 1908.

Describes the occurrence of topaz, specular hematite, garnet, and bixbyite in the cavities of the rhyolite of Topaz mountain. C.

WATER.

Buried Channels Beneath the Hudson and Its Tributaries. By J. F. KEMP. Am. Jl. of Sci. Vol. XXVI., Oct., 1908. Pp. 301–323, with 18 figs.

Discussion mainly of physiographic and theoretical interest, but data utilized in paper were gathered by Board of Water Supply of the City

of New York and interesting points relative to their operations and the water supply are brought out. C.

The Water Powers of Wisconsin. By L. S. SMITH. Wis. Geol. and Nat. Hist. Surv. Madison, Wis. 1908. Pp. xviii + 354, with 54 plates and 17 figs.

A full description of the Wisconsin rivers with valuable tables of statistics of stream measurement, description of the present power plants with suggestions for further development of water power. C.

REGIONAL REPORTS.

Annual Report of the State Geologist of New Jersey for the Year 1907. H. B. KÜMMEL, State Geologist. Geol. Surv. of N. J. Pp. 192, illustrated. Trenton, N. J., 1908.

Administrative report; reports on proposed inland waterway (86 pages); petrography of the Newark igneous rocks (72 pages); notes and statistics on mineral industries of the State. L.

The Mineral Resources of Canada. 10 pp., 32 illustrations and map. Published by Can. Min. Jour., Toronto, 1908. C.

The Mineral Resources of the Philippine Islands. Issued by W. D. SMITH. Bureau of Science, Manila, 1908. 39 pp., 6 plates, and 2 maps.

Contents: Introduction; The non-metallic minerals by W. D. Smith; Metallic mineral resources, by M. Goodman; Statistics; Mining and geologic notes on a portion of northwestern Mindanao, by H. M. Tokio; Mining prospects on and near the Zamboanga peninsula, by W. D. Smith; Summary of the chief characteristics of Philippine ores, by W. D. Smith; Summary of the chief characteristics of Philippine coals, by A. J. Cox. C.

Geological Report on the Patua Ranges, Egmont, National Park. By N. D. COCHRANE. New Zeal. Mines Rec. April 16, 1908, pp. 388–393, with a sketch map.

Describes topography of the region, and the gold veins (reefs) the rocks, and discusses genesis of the ores. C.

Indiana. Department of Geology and Natural Resources. Thirty-second Annual Report. W. S. BLATCHLEY, State Geologist. Pp. 1258, illustrated. Indianapolis, Indiana, 1908. L.

Preliminary Report on a Portion of the Main Coast of British Columbia and Adjacent Islands included in New Westminster and Nanaimo Districts. By C. E. LEROY. Canada Geol. Surv. Report No. 996, 1908. Pp. 56, with colored map.

Describes general and economic geology. L.

Preliminary Report on a Part of the Similkameen District, British Columbia. By C. CAMSELL. Canada Geol. Surv. Report No. 986. Pp. 41, with colored map, 1907.

General physiography and geology, with details of coal occurrence, pp. 1–32.

Ore deposits of gold and copper, described, pp. 22–37.

Brief notes on the Bear Creek mineralized belt, pp. 37–41. L.

ORE DEPOSITS AND RELATED SUBJECTS.

Diffusion as a Factor in Ore Deposition. Continued discussion by H. H. KNOX of paper by L. T. WRIGHT. Min. and Sci. Press. Vol. XCVII., No. 13, p. 421, 1908.

Further argument in favor of Soret's principle. L.

The Distribution of the Elements in Igneous Rocks. By H. S. WASHINGTON. Trans. A. I. M. E. Bi. Mo. Bull. No. 23, pp. 809–838, 1908.

Considers the general chemical composition of igneous rocks, their average composition, petrographic provinces and their distribution, the correlation of the elements with certain type magmas, and concludes with considerations of the practical value of such correlation. L.

Genesis of Rocks and Ores. By B. SYMONS. Pp. 493; illustrated. 5 x 7½ in., cloth, $3. London, 1908. The Mining Journal.

Contents: Sedimentation of rocks and ores. Metamorphism of strata. Segregation of metallic ores in veins. L.

Ore Bodies Without Walls. Communication by F. J. H. MERRILL. Min. and Sci. Press. Vol. XCVII., No. 14, p. 455, 1908.

Mentions four results of observations in Sonora, Mex., on the variations of ore bodies in shear zones with respect to different kinds of country rock. L.

UNCLASSIFIED.

La funzione pratica della Geologia. By F. SACCO. Boll. Soc. Geol. It. XXVI., 1907. (Outline in Geol. Zentralb., Bd. 11, No. 11, p. 488, 1908.)

Recalls importance of lithoidal materials and geologic phenomena upon the development of primitive man and the more ancient civilizations, then reviews the practical reports which exist between the different branches of human activity and the various branches of geology. L.

General Index to Reports of Geological Survey of Canada, 1885–1906. Compiled by F. J. NICOLAS. Pp. 1014. Ottawa, 1908. L.

The Mineral Industry During 1907. Vol. XVI. Edited by W. R. INGALLS. Pp. x + 1127, illustrated. 6¼ x 9¼ in., cloth. Price $10 or 42 s. New York and London, 1908. Hill Publishing Co.

The production, distribution, and uses of metallic and non-metallic products discussed by competent authorities. Contains a review of the literature on Ore Deposits in 1907 by J. F. Kemp, pp. 934–943. C.

A Pocket Handbook of Minerals. By G. M. BUTLER. Pp. 298, illustrated. 4 x 7 in., leather, $3. New York, 1908: John Wiley & Sons; London: Chapman & Hall, Ltd.

Designed to occupy the field midway between works on mineralogy and handbooks on the subject. (Reviewed in ECONOMIC GEOLOGY, Vol. III., No. 5, p. 538.) L.

Short Talks on Mining Law. XII. By A. H. RICKETTS. Eng. and Min. Jl. Vol. 86, No. 18, pp. 851–852, 1908.

Explains eminent domain, the statute of limitations and legal proceedings. L.

SCIENTIFIC NOTES AND NEWS[1]

W. H. EMMONS, of the United States Geological Survey, is giving a course in petrography at Chicago University, and after the holidays will lecture there on economic geology.

THE ILLINOIS STATE GEOLOGICAL SURVEY issued recently Bulletin No. 8, the yearbook for 1907. It is a volume of 390 pages, containing, besides the administrative report by Director H. F. Bain, about 30 papers by members of the State Survey.

DELEGATES FROM THE UNITED STATES GEOLOGICAL SURVEY to the American Mining Congress which met at Pittsburg, December 2, were G. O. Smith, C. W. Hayes, E. W. Parker, G. H. Ashley, J. A. Holmes, H. M. Wilson and C. A. Fisher.

AN IMPROVED OPEN-SIGHT ALIDODE, invented by L. C. Graton, of the United States Geological Survey, and made by Bausch & Lomb, is receiving the approval of geologists and topographers. It consists of an aluminum ruler on which is mounted a box compass and two extra long folding sights. The high sights, and combination of alidode and compass, are a marked advance in the usefulness of a simple instrument.

THE SIXTIETH MEETING OF THE AMERICAN ASSOCIATION for the Advancement of Science will be held in Baltimore, December 28, 1908, to January 2, 1909.

THE OKLAHOMA GEOLOGICAL SURVEY, which was established last spring, with C. N. Gould as director, has the following reports in preparation, viz:

1. A Preliminary Report on the Building Stone of Oklahoma, by Chas. N. Gould.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

2. A Preliminary Report on the Oil and Gas Resources of Oklahoma, by L. L. Hutchinson.

3. A Preliminary Report on the Road Material of Oklahoma, by Chas N. Gould.

4. A Preliminary Report on the Economic Products of the Arbuckle Mountains, by Chas. N. Gould and Chester A. Reeds.

It is expected that these reports will be submitted to the commission for printing at the time of the convening of the next legislature.

AT A MEETING OF THE GEOLOGICAL SOCIETY of Washington, held on Wednesday, October 28, the following papers were read:

Mr. Waldemar Lindgren, New Occurrence of Willemite and Anhydrite; Mr. Bailey Willis, Lines of Inference in Paleogeographic Study; Mr. W. W. Atwood, Geological Studies in the Alaskan Peninsula.

AT A MEETING OF THE NEW YORK ACADEMY OF SCIENCES, held November 16, 1908, the following papers, of interest to readers of ECONOMIC GEOLOGY, were read: On the Electrolytic Refining of Iron, Dr. E. F. Kern; Notes on a Visit to the Iron and Steel Plants of Sydney, Nova Scotia, Metallography applied to a Problem in Ore-dressing, Dr. W. Campbell.

PROF. ALBRECHT F. K. PENCK, of the University of Berlin, delivered the Siliman lectures at Yale University during the month of November. His lectures were concerned with problems connected with glacial geology.

PROFESSOR JOHN J. STEVENSON, having resigned the chair of geology in New York University, requests his correspondents to note that hereafter his address will be 568 West End Avenue, New York, U. S. A.

MR. ROSWALD H. JOHNSON during the past year pursued courses in geology at Columbia University, giving his special attention to oil and gas. Following a season of field work in eastern districts, he has opened an office as consulting geologist in Bartellsville, Okla.

INDEX TO VOLUME III.

[NOTE.—In this index the titles of principal papers and the headings of departments, as *Discussion,* are in italics.]

Actinolite, 624
Addicwell gray shale, 596
Adherence test, for coking coals, 265; method of conducting, 266
Adhesion scale, for testing coking coal, 267
Adirondack magnetite iron ores, 664
Alaskitic rocks, 691
Albite, 623
Algæ, in formation of coal, 298
Allochthonous theory, of coal formation, 293
Alluvial deposits, of China, 9
Alteration, of rocks, 374; by hot solutions, 381; by weathering, 381; pneumatolytic, in Cornwall, 374
Alunite, 616
American Cement Company, view of plant of, 65
American mining congress, proceedings, 445
Ammonia, in Scotch oil shales, 583, 589
Analyses (*see* Chemical analyses)
Andalusite, 624
Anderson, C., analysis of torbanite, 586
Andesite, 469, 690
Andrews, E. B., on the Pittsburg coal, 183
Andrews, E. C., discussion by, 643
Antimony, in Mexico, 683
Aplite, 603
Aquamarine, 624
Archean, so-called, of China, 6
Arkansas, A new discovery of peridotite in (Purdue, 525)
Arnold, R., review of paper by, 232
Arnold, R., and Anderson, R., review of papers by, 231, 232
Athens Co., Ohio, section in, 190
Autochthonous theory, of coal formation, 294

Bacteria, action on vegetable tissue, 304
Bagg, R. M., Jr., *Some copper deposits in the Sangre de Christo Range,* Colorado, 739
Bain, H. F., *Geology of Illinois petroleum fields,* 481; reviews by, 231, 441, 445, 657; on relations of minerals, 614
Ballagan beds, 591
Barite, 616
Barlow, A. E., on diabase-gabbro in Ontario, 601
Barracks shale, 597
Basal conglomerate, 41
Bassler, R. S., *Cement materials of western Virginia,* 503
Bayley, W. S., reviews by, 155, 157, 438; discussion by, 535
Bearpaw shale, 89–96
Beck, R., on ore deposits, 424, 478; at vein intersections, 153; of Andreasberg, 331
Becker, G. F., on filtration of mineral solutions, 750
Bell, R., on cobalt conglomerate, 608
Bellaire, Ohio, section near, 186
Belle Isle, Newfoundland, iron ores of, 286
Belmont Co., Ohio, sections in, 186, 187
Belt, Mont., section of Kootenai formation at, 80
Bersbo mine, 639
Bertrand, C. E., on formation of coal, 296, 297
Bibliography, of the Scotch oil shale fields, 598
Big Elk Creek, section of Montana group, 91
Bighorn basin region, Wyo., Cloverly formation of, 84
Binny sandstone, 597
Bjorkstedt, W., analysis of iron ore, 472; of garnet, 473; of limerock, 477
Bladen, Ohio, section near, 196
Blatchley, W. S., on petroleum in Illinois, 482, 487
Bleininger, A. V., review by, 658
Boehmer, M., discussion by, 337
Bog ores, of Quebec, 287
Boghead mineral, 584
Bonanza, defined, 144

Borax beds, in the Andes, 652
Bornite, 631–635
Bownocker, J. A., on oil sands, 488
Bownocker, J. A., and Condit, D. D., *The Pomeroy coal in Ohio*, 183
Branner, J. C., and Brackett, A. N., on peridotite in Arkansas, 526
Bridgeport sand, 484
Bridger, Mont., section of Montana group at, 94
Brief review of the mining industry of Mexico (Ordoñez), 677
Briggs, L. J., on filtration of soil solutions, 750
British Columbia, iron ores of, 278
Brock, R. W., on magnetites, of Ontario, 279
Brooks, A. H., on placers, 13
Brown ore type, of iron ores, 286
Brown, C. N., section by, 187
Brown, C. S., *The lignite of Mississippi*, 219; review of paper by, 164
Broxburn marl, 596
Broxburn shale, 596
Buchanon sand, 484, 487
Buckley, E. R., on iron ores, of Missouri, 285
Buena Vista shale, 511
Bunches, defined, 144
Burchard, E. F., on Clinton ores, of Alabama, 285; review by, 553
Burdiehouse limestone, 591, 597
Burrows, A. G., analysis of graywacke slate by, 608
Burrows, J. S., review of paper by, 441
Butler, G. M., review of paper by, 438
Butte, Mont, ore shoots at, 326

Calcareous replacement deposits, 497
Calciferous sandstone, of Scotland, 589, 591
Campbell, M. R., *A practical classification for low-grade coals*, 134; on amount of coals in Appalachians, 27; on the classification of coals, 135; on transformation of vegetable matter into coal, 137; on coal sampling, 189
Canada, The iron ores of (Leith), 276
Carbonate type, of iron ores, 286
Carter, O. C. S., on copper mines, 737
Casey sand, 488
Catlett, C., analyses by, 516
Celestite, 616
Cement, natural, 71, 522 (*see also* Portland cement, hydraulic cement)
Cement, testing of, 71
Cement and Portland cement materials of Mississippi (Crider), review of, 553
Cement belt in Lehigh and Northampton Counties, Pa., geology of (Peck), 37
Cement industry, 57; in Virginia, 523
Cement materials of western Virginia (Bassler), 503; of Mississippi, 553
Cement rock, of Lehigh district, character of, 47; distribution of, 55; origin of, 55
Chalcocite, 626, 630–635
Chalcopyrite, 631–635
Chamberlin and Salisbury, on fusion, 423
Chance, Wyo., section of Montana group near, 96
Chemical analyses—ash of oil shale, 588; cement rock, 49, 513; clay, red residual, 116; coal, 18, 25–26, 189–197, 310; dolomite, 42; garnet, 473; graywacke slate, 608; ilvaite, 474; iron ore, 472; kaolin, 114; lignites, 223; limerock, 477; limestone, 43, 513–517, 521; monzonite porphyry, 387; paleozoic shales, 608; torbanite, 586
Chimneys, defined, 144
China, mineral resources of (Willis), 1, 118; mining in, 1; physiography of, 4; compared as to geologic conditions with U. S., 5; map of, 6, 126; petroleum in, 125 (*see also* North China and South China)
Church, J. A., discussion by, 428
Chute, defined, 144
Claggett formation, 89–96
Clapp, C. H., *Recent literature on economic geology*, 100, 167, 252, 348, 764
Clark, F. W., review of paper by, 243
Classification, genetic, of minerals (Emmons), 611
Classification, practical, for low-grade coals (Campbell), 134; discussion of, 647
Clay, red residual, analysis of, 116
Clay deposits, of Dry Branch region, Ga., structure of, 111; origin of, 112
Clays, in China, 29; of Mississippi (Logan), review of, 230
Cleavage, in coal, 139

Clifton-Morenci porphyry, composition diagrams of, 390–396; alteration of, 393
Clinton sedimentary type, of iron ore, 285
Cloverly formation, 84–87; sections of, 85
Coal, analyses of, 18, 25–26, 189–197, 309; in China, 15–27, 32–36, 120, 128; amount of, in China, 27; in Appalachians, 27; anthracitization of, 315; illustrations of, 138 (pl. 4); fracture of, on drying, 139; metamorphism of, 314; Pomeroy, in Ohio, 183; Redstone, 183; weathering of, 137
Coal, the formation of, Some problems of (White), 292
Coal fields, of China, 8, 15–27; of Manchuria, 25
Coal measures of China, 8–9
Coalification, 303, 311
Coal-mine sampling, 441
Coals, of Kootenai formation, 86
Coals, coking, a practical test for (Pishel), 265
Coals, low-grade, A practical classification for (Campbell), 134
Cobalt, occurrence in Ontario, 600
Cobalt-silver ores of northern Ontario, Origin of (Hore), 599
Coking coals, a practical test for (Pishel), 265
Coking tests, table of results, 268
Coldre, L., on deep wells, in China, 121
Coleman, A. P., on glaciated pebbles, in Cobalt conglomerate, 607
Coleman, A. P., and Willmott, A. B., on Michipicoten iron ores, 283
Contact deposits, in Mexico, 680
Copper, The relation of, to pyrite in the lean copper ores of Butte, Montana (Simpson), 628
Copper, at Mineral, Idaho, 492; in China, 129; in Mexico, 683
Copper and gold mine, Mt. Chalmers, Queensland, 246
Copper deposits, Newark, of southeastern Pennsylvania (Wherry), 726
Copper deposits in the Sangre de Christo Range, Colorado (Bagg), 739
Copper deposits of Kasaan Peninsula, Alaska (Wright), 410
Copper handbook, vol. VII. (Stevens), review of, 542
Copper mines, early, 727; localities of, 728
Copper ores, of Cornwall, occurrence of, 372; genesis of, 377; of Butte, Mont., 628–636; of Kasaan Peninsula, Alaska, 414; of Scandinavia, 637
Copper Queen intrusion, 694
Copperopolis, Cal., ore deposits of, 340
Cornwall, Geological aspect of the lodes of (MacAlister), 363
Cornwall, antiquity of mining in, 363; geological description of, 365; stratigraphical table of, 368; lodes of, 369; tin and copper ores of, 364, 369; silver-lead veins of, 378
Coromandel subdivision, Auckland, geology of, 438
Covellite, 626
Cow Creek, Mont., section of Montana group on, 89
Crider, A. F., review of paper by, 553
Cross, W., on Montana group, 87; on granites of the Rocky Mts., 742
Crystallization, order of, in rocks of Velardeña, 701, 708, 709
Cuencamé valley, Mexico, 688

Dale, T. N., review of paper by, 157
Darton, N. H., on the Cloverly formation, 84
Davis, C. A., review of paper by, 248; on peat bogs, 316
Deformation, in Lehigh district Pa., 52
De Launay, on ore shoots, 154
Depth, of copper ore, 640
Density, porosity, and moisture, The relation of, to the specific volume of ores (Mead), 319
Deposition, of ores, at Mineral, Idaho, 501
De Wolf, F. W., review by, 164
Diabase, 692
Diabase-gabbro, 600
Diagram, illustrating relation of density, porosity, and moisture, to specific volume of ores, 319 (pl. 8), 322; of chemical composition of Clifton-Morenci porphyry, 388–392; of chemical changes in altered igneous rock, 395, 396, 402
Dial-compass, 216
Diamonds, in Arkansas, 526
Dikes, basalt, effect on ore deposits, 502
Diorite, 469, 692
Dioritic rocks, 692

Discussion—
Broken Hill silver mine, New South Wales (Andrews), 643
The classification of low-grade coals (Grout), 647
The localization of values or occurrence of shoots in metalliferous deposits (Irving), 143; (Smith), 224; (Sales), 326; (Ransome), 331; (Boehmer), 337; (Winchell), 425; (Stirling), 534; (Sjögren), 637
Mineral resources of China (Church), 428
Note on the occurrence of graphite schist in Tuxedo Park, N. Y. (Bayley), 525; (Stewart), 538
On the Ray mining district, Nevada (Turner), 538
The ore deposits of Copperopolis, Cal. (Reid), 340
The oxidation of pyrite (Grout), 532
Peat, its origin, uses, and distribution in Michigan (Lane), 431
A theory of ore-deposition (Ransome), 420; (Jaggar), 529
Donath, E., on formation of coal, 313
Drake, N. F., on coal, in China, 16, 20; on iron ore, in China, 27
Drilling wells, in China, 124
Dry Branch region, Ga., Kaolins of (Veatch), 109
Duncanville sand, 484
Dunnet shale, 597
Dunstan, B., review of paper by, 246

Eagle formation, 88–96
Eckel, E. C., on Clinton ores, of Alabama, 285
Economic geology, Recent literature on (Clapp), 100, 167, 252, 348; (Loughlin), 446, 558, 667; (Loughlin and Clapp), 764
Editorial, 418
Eldridge, G. H., on Montana group, 87
Eldridge, G. H., and Arnold, R., review of paper by, 231
Ellis, A. J., review by, 437
Emmons, S. F., on orographic movements, 743
Emmons, W. H., *A genetic classification of minerals*, 611
Enargite, 631–635
Endlich, F. M., on Sangre de Christo Range, 740
Erzlagerstätten von Pitkärante am Ladoga-See (Trüstedt), review of, 540
Everhart, E., analysis of kaolin by, 114
Experiments on the separation of the constituents of a solution by filtration through a mineral filter (Sullivan), 750

Fall Line clays, 109
Falu mine, 637
Fault fissures, character of, 148
Fayol, on formation of coal, 293
Fell's shale, 596
Ferric sulphate solutions, experiments with, 751
Filtration through a mineral filter, Experiments on the separation of the constituents of a solution by (Sullivan), 750
Finlay, J. R., on ore deposits, in Idaho, 334
Fisher, C. A., *Southern extension of the Kootenai and Montana coal-bearing formations in northern Montana*, 77
Fissure veins, in China, 10
Fissures, gouge-filled, 331; ore-bearing, 331–337
Fleck, H., and Haldane, W. G., review of paper by, 159
Fluorite, 614
Formation of coal, Some problems of (White), 292
Fossil iron ores of Georgia (McCallie), review of, 757
Franklinite, 622
Fraser, C., review of paper by, 438
Frazer, P., on classification of coals, 134
Fuller mill, for grinding cement materials, 67

Gallia Co., Ohio, sections in, 198
Garfield, J. R., review of paper by, 242
Garneill, Mont., section of Kootenai formation near, 82
Garnet, 473, 701
Garry, G. H., *Ore-deposits of the Velardeña district, Mexico*, 688
Gas and salt wells, in China, 121
Gautier, A., on thermal waters, 422
Gehlenite, 708
Geikie, A., on fusion, 423
Genesis, of coals, factors of, 292; of the copper-tin ores of Cornwall, 377; of magnetite ores of Shasta

Co., Cal., 476; of the ore minerals at Heroult, Cal., 476; of ores at Mineral, Idaho, 501; of ores in Velardeña district, Mexico, 713; of copper ores in Sangre de Christo Range, Colo., 747
Genetic classification of minerals (Emmons), 611
Geological and economic work, magnetic observations in (Smyth), 200
Geological aspect of the lodes of Cornwall (MacAllister), 363
Geological relations of the Scandinavian iron ores (Sjögren), review of, 658
Geology, of China, 6; of Lehigh and Northampton Counties, Pa., 38; of the Dry Branch region, Ga., 109; of Kasaan Peninsula, Alaska, 410; of Heroult region, Shasta Co., Cal., 466; of eastern Illinois oil fields, 483; of Mineral, Idaho, 493; of western Virginia, 506–519; of the Scotch oil shales, 584; of Newark copper deposits of Pennsylvania, 729; of the Sangre de Christo Range, Colo., 739
Geology and origin of the Lapland iron ores (Stutzer), review of, 545
Geology of Illinois petroleum fields (Bain), 481
Geology of the Adirondack magnetite iron ores (Newland), review of, 664
Geology of the cement belt, in Lehigh and Northampton Counties, Pa. (Peck), 37
Geology of the Coromandel subdivision, Hauraki, Auckland (Fraser), review of, 438
Georgia, Kaolins of the Dry Branch region (Veatch), 109
Glass materials, in China, 29
Gold, in China, 10, 131; in Manchuria, 14; in Pennsylvania, 732
Gold-bearing rocks, of China, 6
Gold values, in the Klondike gravels, 650
Gouge-filled fissures, 331
Granite, pneumatolytic changes in, 374
Granites of Maine (Dale), review of, 157
Grano-diorite, 469
Graphic comparison of the alteration of rocks by weathering with their alteration by hot solutions (Steidtmann), 381
Graphic comparison of chemical and mineralogical changes, method of, 384
Graphite, algal origin of, 298
Graphite schist, in Tuxedo Park, N. Y., 535
Graton, L. C., review by, 542
Gravels, of the Klondike, 650
Graywacke, 609
Graywacke slate, analysis of, 608
Great Falls region, coal deposits of, 78; Kootenai formation of, 80
Great Fitzroy copper and gold mine, Mount Chalmers, Rockhampton district (Dunstan), review of, 246
Griswold, W. T., review of paper by, 231
Griswold, W. T., and Munn, M. J., review of paper by, 232
Grand'Eury, on the formation of coal, 294
Greenbrier limestone, 504
Greenstone, 376
Grout, F. F., discussion by, 532, 647; on the classification of coals, 135; on formation of coal, 318
Guardarraya intrusion, 694
Gümbel, K. von, on formation of coal, 297
Gwynedd formation, 729
Gypsum Creek, Wyo., section of Cloverly (Kootenai) formation on, 85

Haanel, E., on location of ore deposits, 201
Hague, A., on Montana group, 88
Hardman, J. E., on magnetite, of New Brunswick, 280
Harrisburg peneplain, 40
Hartford, W. Va., section at, 195
Hedenbergite, 473
Hess, F. L., review by, 159
Hillebrandite, 707
Hills, R. C., on the Sangre de Christo formation, 743; on ore deposits in Sangre de Christo Mts., 745
Holden, R. J., review by, 757
Holmes, T. R., on the Island of Ictis, 364
Honorable Peter White, a biographical sketch of the Lake Superior iron country (Williams), review of, 155
Hoover, H. C., on metal mining, in China, 7, 10; on gold, in China, 14; on coal, in China, 17
Hore, R. E., *Origin of cobalt-silver ores of northern Ontario*, 599

Hosie, A., on Manchuria, 3, 14
Hot solutions, action on igneous rocks, 397
Houston coal, 596
Houston marls, 595
Hudson River slate, Pa., 51
Huerfano formation, 743
Hurlet limestone, 591, 595
Hyde, J. E., section by, 186
Hydraulic cement, discovery of, 57; manufacture of, 584
Hypothesis and theory, distinction between, 425

Iddings and Weed, on Montana group, 88
Igneous phenomena, at Velardeña, Mexico, 724
Igneous rocks, of China, 9; of Velardeña, Mexico, 692
Illinois, geological structure of, 486
Illinois petroleum fields, Geology of (Bain), 481
Ilvaite, 473, 624
Importance of uniform and systematic coal-mine sampling (Burrows), review of, 441
Impounding of mineralizing solutions, 150
Ingalls, W. R., review of book by, 656, 759
Intersecting veins, 153
Intrusions, in Velardeña district, Mexico, 693
Intrusive rocks, of Kasaan Peninsula, Alaska, 411
Intrusives, in diabase-gabbro, in Ontario, 601
Iowa Geological Survey, Annual report, Vol. XVII., 1906, review of, 657
Iron lodes, of Cornwall, 378
Iron ore, analysis of, 472
Iron ore deposits, types of, 276
Iron ore formations, of China, 7
Iron ore reserves, 289
Iron ores of Canada (Leith), 276
Iron ores, of Adirondacks, 664; of Canada, 276; of China, 27–29, 128, 428; of Lapland, 545; of Lehigh Valley, Pa., 37; of Newfoundland, 286; of Ontario, 279, 280; of Scandinavia, 658
Irving, J. D., discussion by, 143

Jaggar, T. A., discussion by, 529
Jameson, C. D., on coal and iron, in eastern China, 27
Jeffersonite, 622
Judith basin region, Kootenai formation in, 81
Judith River beds, 89–96
Judith River region, formations of, 88

Kaolin, analysis of, 114; as alteration product, 394
Kaolins of the Dry Branch region, Ga. (Veatch), 109
Kasaan Peninsula, Alaska, The copper deposits of (Wright), 410
Kasaan Peninsula, Alaska, geology of, 410; intrusive rocks of, 411; ore deposits of, 413
Keewatin formation, 605
Keewatin-Huronian rocks, role in precipitating ores, 605
Keewatin iron ores, 284
Keith, A., on magnetites, of North Carolina, 279
Kemp, J. F., on localization of values, 152; on magnetites, of New York, 279; of Pennsylvania, 279; on contact deposits, 476; on ore deposits, 479; translation by, 677
Killas, 375
Kilns, for cement manufacture, 64
Kingsmill, T. W., on coal, in China, 32
Kirkwood sand, 484, 489
Kittatinny dolomite, 41
Kittatinny valley, physiography of, 40
Klondike high level gravels, 650
Knight, C. W., review of paper by, 242
Knopf, A., review by, 540
Kolbeck, F., on porphyry rocks, in China, 132
Kootenai and Montana coal-bearing formations in northern Montana, Southern extension of (Fisher), 77
Kootenai formation, 78; sections of, 80–83
Kunz, G. F., and Washington, H. S. on diamonds in Arkansas, 526

Lake Superior iron country, A biographical sketch of (Williams), review of, 155
Lake Superior sedimentary type, of iron ore, 281
Lane, A. C., discussion by, 431
Lansdale formation, 729
Lapland iron ores, 545
Lapparent, A. de, on formation of coal, 294
Lasalle anticline, 486
Launay, L. de, on ore deposits, 421

Law, mining, mineral, and geological, 433
Lawrence Co., Ohio, sections in, 199
Lead, in China, 130
Lead and zinc in the United States (Ingalls), review of, 656, 759
Leadville, Colo., instances of secondary enrichment, 338
Leclère, A., on geology of southern China, 126
Le Conte, J., on fusion, 423
Lehigh County, Pa., physiography of, 38
Leith, C. K., *The iron ores of Canada*, 276; review by, 658; on pegmatite type of ores, 643
Leith, C. K., and Harder, C. E., on iron ores, in Utah, 277
Leonard, A. G., review of report by, 762
LePrince-Ringuet, F., on geology of North China, 22, 32
Lesley, J. P., on anthracitization, 315
Lewis, J. V., on New Jersey copper deposits, 726
Lewiston limestone, 504
Liberty Hall limestone, 511
Lignite, application of term, 136; analyses of, 223
Lignite of Mississippi (Brown), 219; review of, 164
Limestones, analyses of, 513, 516, 517, 521
Lindgren, W., on ore deposits, in Idaho, 331; on ores of the Clifton-Morenci district, 383; on ilvaite, 473; on production of silver, 492; on geology of Mineral, Idaho, 496; on formation of minerals, 611; on classification of minerals, 612; on instability of soda salts, 623; reviews by, 650, 652, 653
Lindgren, W., and Ransome, F. L., on ore deposits, in Colorado, 332; on filtration of mineral solutions, 750
Lines, E. F., reviews by, 230, 762
Literature on economic geology, Recent (*see* Recent literature etc.)
Localization of values in ore-bodies, 143, 224
Loezy, L. von, on sections, in China, 118; on coal, in China, 121
Lodes, of Cornwall, structure of, 370
Lodes of Cornwall, Geological aspect of (MacAlister), 363
Logan, W. N., review of paper by, 230
Londonderry ores, of Nova Scotia, 287
Loess, of China, 9
Los Muertos formation, 689
Lothians, columnar section in, 590
Loughlin, G. F., *Recent literature on economic geology*, 446, 558, 667, 764
Lower Huronjan formation, 606
Low-grade coals, A practical classification for (Campbell), 134
Lyman, B. S., on copper in Pennsylvania, 726

MacAlister, D. A., *Geological aspect of the lodes of Cornwall*, 363
McCallie, S. W., review of work by, 757
McCloud formation, 470
McConnell, R. G., review of paper by, 650
McMechen, F. L., review of paper by, 437
Macon, Ga., clay mines near, 109
Magmas, 422, 696, 701
Magmatic segregation type, of iron ore, 277
Magnesian limestone, for cement, 45
Magnetic observations in geological and economic work (Smyth), 200
Magnetic sands, 287
Magnetic strip, survey of, 213
Magnetite, 472, 622
Magnetite deposits, 279, 470
Magnetite ores of Shasta Co., Cal., Occurrence and genesis of (Prescott), 465
Magnetometer, construction and use, 200; figure of, 200
Manchuria, gold in, 12
Maps—North and central China, 6 (pl. 1); cement belt of Pennsylvania, 55 (pl. 2); clay deposits of Macon, Ga., 110; central and south China, 126 (pl. 3); Cornwall, England, 366; Kasaan Peninsula, Alaska, 415; northern California, 465; Heroult, Shasta Co., Cal., 467; oil pools in eastern Illinois, 482 (pl. 9); mineral, Idaho, 494; Virginia, showing Ordovician outcrops, 508; T. 8S., R. 25W., Arkansas, 525; southern Scotland, 578; Pennsylvania copper deposits, 729 (pl. 13).
Maps, representation of features on, 431
Marcasite, 533
Mead, W. J., *The relation of density, porosity, and moisture to the specific volume of ores*, 319; review by, 664
Medina beds, Pa., 52

Meigs Co., Ohio, sections in, 190, 191
Mercury, in China, 131
Metalliferous deposits, localization of shoots in, 143
Metallographic provinces, 421
Metallography, 628
Metamorphism, of coal, 314; of dioritic intrusives, 698, 704; of alaskitic rocks, 705; of limestone, 706, 709; in Velardeña district, Mexico, 710
Metasomasis, in Cornwall, 374
Mexico, mining industry of, a brief review of (Ordoñez), 677
Mexico, Velardeña district, Ore-deposits of (Spurr and Garrey), 688
Michipicoten iron ores, 283
Miller, W. G., on cobalt-silver ores, 599, 605
Miller, W. G., and Knight, C. W., on cobalt-silver ores, 606
Mineral, Idaho, Ore deposits at (Turner), 492
Mineral, Idaho, geological map of, 494; section at, 495
Mineral resources of China (Willis), 1, 118; discussion of (Church), 428
Mineral resources of the United States for the calendar year 1906, review of, 343
Mineral specific gravity, defined, 320
Mineralizing solutions, impounding of, 150
Minerals, A genetic classification of (Emmons), 611
Minerals, of Heroult, Shasta Co., Cal., 472
Mining, in Cornwall, antiquity of, 363
Mining conditions, in Mexico, 685
Mining congress, American, proceedings, 445
Mining industry of Mexico, A brief review of (Ordoñez), 677
Mining, mineral, and geological law (Shamel), review of, 433
Mississippi, The lignite of (Brown), 219; cement materials of, 553
Missouri, iron ores of, 285
Montana, Kootenai coal-bearing formations of, 77
Montana group, 87; section on Cow Creek, Mont., 89
Monterey County, Cal., coal from, 140
Monzonite, 693
Mortar test, for coking coal, 265
Moss, H. R., analysis of ilvaite by, 474
Mungle shale, 595
Murat limestone, 511, 515
Musselshell River region, Kootenai rocks of, 83; Montana group in, 90

Nason, F. L., on graphite, 535
Natural Bridge limestone, 511
Natural cement, 71, 522
Natural gas, in Illinois, 481, 489
Nests, defined, 144
Nevada, Ray mining district, 538
New discovery of peridotite in Arkansas (Purdue), 525
Newark copper deposits of southeastern Pennsylvania (Wherry), 726
Newark series, 726
Newberry, J. S., on Kootenai series, 79
Newfoundland, iron ores of, 286
Newland, D. H., review of paper by, 664
Norristown formation, 729
North China, 6–30; rocks of, 6
North Dakota Geological Survey, Fourth biennial report, review of, 762
Northampton County, Pa., physiography of, 38
Nova Scotia, Londonderry ores of, 287

Obrutchoff, W., on sections in China, 118
Occurrence and genesis of the magnetite ores of Shasta Co., Cal., (Prescott), 465
Oil industry, of Scotland, nature of, 573; extent of, 574; origin of, 575; minerals used in, 577; location of, 577; history of, 578
Oil sands, of Illinois, correlation of, 488
Oil shale, of Scotland, 587
Oil shale field, of Scotland, structure of, 593; sections of, 594
Oil-bearing formations, of southern California, correlation of, 237
Oneida beds, Pa., 52
Ontario, iron ores of, 279, 280
Ontario, northern, cobalt-silver ores of, Origin of (Hore), 599
Ordoñez, E., *A brief review of the mining industry of Mexico,* 677
Ore-chute, defined, 225
Ore-deposition, theory of, 420, 529; at Mineral, 501
Ore deposits at Mineral, Idaho (Turner), 492

Ore-deposits of the Velardeña district, Mexico (Spurr and Garrey), 688
Ore deposits, of Copperopolis, Cal., 340; of Kasaan Peninsula, Alaska, 413; of Mineral, Idaho, 496; of Pitkäranta, 540; of Velardeña district, Mexico, 678, 712; of Sangre de Christo Range, Colo., 745
Ore shoots, at Butte, Mont., 326; at Leadville, Colo., 339; origin of, 426
Ores, cobalt-silver, of northern Ontario, Origin of (Hore), 599
Origin, of cement rock of Lehigh region, 55; of kaolins of Georgia, 115; of graphite at Tuxedo Park, N. Y., 537; of disseminated ore in Cobalt district, Ont., 603; of iron ores of Sweden, 643; of ores at Broken Hill, N. S. Wales, 846; of ore deposits in Velardeña district, Mexico, 713; of Newark copper ores in Pennsylvania, 737; of copper ores in Sangre de Christo Range, Colo, 746
Origin of cobalt-silver ores of northern Ontario (Hore), 599
Oxychlorid of magnesia process, for cement-making, 45

Pagina intrusion, 694
Paleozoic, of China, 8
Paragenesis, 475, 628
Paragenetic ore shoots, 426
Paramorphism, 711
Parr, S. W., on the classification of coals, 135
Parsons, W. B., on coal, in China, 34
Pay-shoots, defined, 145
Peat, essays on its origin, uses, and distribution in Michigan (Davis), review of, 248
Peck, F. B., *Geology of the cement belt, in Lehigh and Northampton Counties, Pa.*, 37
Pegmatite type, of iron ore, 277
Pennington shales, 504
Pennsylvania, cement belt of, 37
Peridotite, A new discovery of, in Arkansas (Purdue), 525
Perkasie formation, 729
Permo-Triassic, of China, 8
Persistent minerals, 623
Petroleum, in China, 125; recent literature on, 231; production in the United States, 232; algal origin of, 298; in Illinois, 481; conditions of occurrence, 487
Petroleum fields, Illinois, Geology of (Bain), 481
Petrologic provinces, 421
Piedmont region, physiography of, 113
Pishel, M. A., *A practical test for coking coals*, 265
Pittsburg coal, in Ohio, 188
Placers, in China, 12
Pneumatolytic alteration, in Cornwall, 374
Pocket handbook of minerals (Butler), review of, 438
Pockets, defined, 144
Pomeroy, Ohio, section at, 193
Pomeroy coal in Ohio (Bownocker and Condit), 183
Pomeroy sandstone, 199
Porosity, of ores, method of determining, 321
Porphyry, composition diagrams of, 390–396; alteration of, 393
Portland cement, composition of, 62; process of manufacture, 63–70
Portland cement rock, analyses of, 513
Postgenetic ore shoots, 426
Potonié, H., on formation of coal, 294, 299
Pottstown formation, 729
Practical classification for low-grade coals (Campbell), 134
Practical test for coking coals (Pishel), 265
Pre-Cambrian, of China, 7
Pre-Cambrian rocks, of Lehigh and Northampton Counties, Pa., 41
Preparation, of material, for metallographic examination, 629
Prescott, B., *The occurrence and genesis of the magnetite ores of Shasta Co., California*, 465
Production, of iron ore, in 1906, 288
Pryor Mountain region, formations in, 93
Pumpelly, R., on rock disintegration, 13; on coal, in China, 34
Pumpherston shales, 591, 597
Purdue, A. H., *A new discovery of peridotite in Arkansas*, 525
Purington, C. W., on fissures, 149; on ore horizons, 151
Pyrargyrite, 625
Pyrite, 630–635, 638; oxidation of, 532
Pyrite, The relation of copper to, in the lean copper ores of Butte, Montana (Simpson), 628
Pyrite ores, of Butte, Mont., 628

Quarry products, Iowa, 657
Quartz, 623
Quartz-tourmaline veins, 499
Quebec, bog ores of, 287

Raeburn shale, 595
Ransome, F. L., discussion by, 331, 420; reviews by, 246, 438, 759
Ray mining district, Nevada, 538
Recent literature on economic geology (Clapp), 100, 167, 252, 348; (Loughlin), 446, 558, 667; (Loughlin and Clapp), 764
Recent literature on petroleum, 231
Red Basin of Ssi-ch'uan, in China, 119; geology of, 120
Redstone coal, in Pa. and W. Va., 183
Refining, of oil, 581
Reichert, F., review of paper by, 652
Reid, C., on the Island of Ictis, 364
Reid, J. A., discussion by, 340
Relation of copper to pyrite in the lean copper ores of Butte, Montana (Simpson), 628
Relation of density, porosity and moisture to the specific volume of ores (Mead), 319
Renault, B., on formation of coal, 296, 297
Replacement, in rocks, 711
Replacement deposits, 497
Report of proceedings of the American mining congress, Tenth annual session, review of, 445
Report of the Iowa Geological Survey, Vol. 17, review of, 657
Reports on gold values in the Klondike high level gravels (McConnell), review of, 650
Resources, Mineral, of China (Willis), 1, 118
Retorting and refining, of oil, 581
Review, Brief, of the mining industry of Mexico (Ordoñez), 677
Reviews—
Annual report, Vol. XVII., 1906, Iowa Geological Survey, Quarry products, Bleininger, 657
Cement and Portland cement materials of Mississippi (Crider), Burchard, 553
Clays of Mississippi (Logan), Lines, 230
The copper handbook, Vol. VII. (Stevens), Graton, 542
Die Erzlagerstätten von Pitkärante am Ladoga-See (Trüstedt), Knopf, 540
Fossil iron ores of Georgia (McCallie), Holden, 757
Fourth biennial report North Dakota Geological Survey 1905–1906 (Leonard), Lines, 762
The geological relations of the Scandinavian iron ores (Sjögren), Leith, 658
The geology and origin of the Lapland iron ores (Stutzer), Spencer, 545
Geology of the Adirondack magnetite iron ores (Newland), Mead, 664
The geology of the Coromandel subdivision, Houraki, Auckland (Frazer), Ransome, 438
The granites of Maine (Dale), Bayley, 157
The Great Fitzroy copper and gold mine, Mount Chalmers, Rockhampton district (Dunstan), Ransome, 246
The Honorable Peter White; a biographical sketch of the Lake Superior iron country (Williams), Bayley, 155
Importance of uniform and systematic coal-mine sampling (Burrows), Bain, 441
Lead and zinc in the United States (Ingalls), Bain, 656; Ransome, 759
The lignite of Mississippi (Brown), De Wolf, 164
Mineral resources of the United States for the calendar year 1906, Watson, 343
Mining, mineral, and geological law (Shamel), Winchell, 433
Peat, essays on its origin, uses, and distribution in Michigan (Davis), 248
A pocket handbook of minerals (Butler), Bayley, 438
Report of proceedings of the American mining congress, Tenth annual session, Bain, 445
Reports on gold values in the Klondike high level gravels (McConnell), Lindgren, 650
Some recent literature on petroleum, Bain, 231
A study of the uranium and vanadium belts of southern Colorado (Fleck and Haldane), Hess, 159
Tests for ores, minerals, and metals of commercial value (McMechen), Ellis, 437

Transvaal Mines Department, report of the Geological Survey for the year 1906, Lindgren, 653
Los Yacimientos de boratos y otros productos minerales explotables del territorio de los Andes (Reichert), Lindgren, 652
Richthofen, F. v., on coal, in China, 15, 16, 23; on iron ore, in China, 28; on clays, in China, 30; on sections, in China, 118
Rito Alto Peak, 740; ores of, 746
Robinson sand, 484
Rock specific gravity, defined, 320
Rogers, H. D., on copper ores, 736
Romney shales, 504

Sales, R. H., discussion by, 326
Salida copper deposits, 745
Salisbury, Pa., section near, 184
Salt wells, in China, 121
Sampling ore-deposits, 227
San Isidora intrusion, 697
Sandberger, F., on ore deposits, 152
Sangre de Christo formation, 743
Sangre de Christo Range, Colorado, Some copper deposits in (Bagg), 739
Sapranthrakon, 290
Saprodil, 299
Sapropel, 299
Sapropelic coals, characterized, 299
Sapropelite, 299
Scandinavian copper and lead-silver mines, 637
Scandinavian iron ores, 658
Scheerer, T., on fusion, 423
Scientific Notes and News, 106, 178, 258, 353, 453, 567, 671, 774
Scotland, The shale oil industry of (Steuart), 573
Scott's Run, W. Va., section on, 184
Secondary enrichment and impoverishment, 337
Sections—Lehigh cement belt, Pa., 54; Kootenai formation at Belt, Mont., 80; at Skull Butte, Mont., 81; at Muddy Creek, Mont., 82; at South Moccasin Mts., 82; Cloverly (Kootenai) formation, on Gypsum Creek, Wyo., 85; near Thermopolis, Wyo., 85; Montana group, on Cow Creek, Mont., 89; near Lebo Creek, Mont., 91; near Bridger, Mont., 94; near Chance, Wyo., 96; Dry Branch region, Ga., 110; near Salisbury, Pa., 184; on Scott's Run, W. Va., 184; Bellaire, Ohio, 186; Belmont Co., Ohio, 186, 187; Athens Co., Ohio, 190; Meigs Co., Ohio, 190, 191; Pomeroy, Ohio, 193; near Hartford, W. Va., 195; near Bladen, Ohio, 196; Gallia Co., Ohio, 198; Lawrence Co., Ohio, 199; across Illinois, 485; Mineral, Idaho, 495; Silver Bell mine, Idaho, 498; between the Blue Ridge and Little North Mt., Va., 506; of middle and upper Ordovician strata in northwestern Virginia, 512; of "The Valley" in southwestern Virginia, 518, 519; in the Powell River valley, Va., 520; of the West Calder shale field, Scotland, 579; of oil shale, at Torbane, Scotland, 586; of the shale fields of Mid and West Lothian, Scotland, 590, 594
Separation of the constituents of a solution by filtration through a mineral filter, Experiments on (Sullivan), 750
Setting, of cement, 72
Shale oil industry of Scotland (Steuart), 573
Shamel, C. H., review of paper by, 433
Shasta Co., Cal., Occurrence and genesis of the magnetite ores of (Prescott), 465
Shenandoah formation, 509
Sherwood limestone, 511
Shoot, defined, 144
Shoots of occurrence, defined, 145, 147; how produced, 147–151
Shoots of variation, defined, 145; how produced, 151–154
Shoots in metalliferous deposits, 143
Silver, at Mineral, Idaho, 492; production of, in Mexico, 681
Silver Bell mine, vertical section of, 498
Silver mines, of Svenningdalen, Norway, 641
Silver-lead ores, of Scandinavia, 637
Silver-lead veins, of Cornwall, 378
Simpson, J. F., *The relation of copper to pyrite in the lean copper ores of Butte, Montana*, 628
Sinian limestone, China, 8
Sjögren (H.), discussion by, 637; review of paper by, 658
Skarn, 469
Skölar, 638
Skull Butte, Mont., section of Kootenai formation, 81

Smith, F. C., discussion by, 224
Smith, H. K., review of paper by, 242
Smyth, A. L., on placers, 13
Smyth, H. L., *Magnetic observations in geological and economic work*, 200
Solution, separation of the constituents of, by filtration through a mineral filter, Experiments on (Sullivan), 750
Solutions, hot, action on igneous rocks, 397
Some problems of the formation of coal (White), 292
Some recent literature on petroleum, review of, 231
South China, geology of, 125; map of, 126
South Moccasin Mts., Mont., section of Kootenai formation at, 82
Southern extension of the Kootenai and Montana coal-bearing formations in northern Montana (Fisher), 77
Spanish Peaks, 743
Specific gravity, of ores, method of determining, 320
Specific volume of ores, The relation of density, porosity, and moisture to (Mead), 319
Spencer, A. C., review by, 545; on magnetite ores, of New Jersey, 279
Spodumene, 624
Spots, defined, 144
Spurr, J. E., discussion of paper by, 420; on ore deposition, 479, 501, 604, 736
Spurr, J. E., and Garrey, G. H., *Ore-deposits of the Velardeña district, Mexico*, 688
Spurrite, 707
Stanton, T. W., on Montana group, 87
Stanton, T. W., and Hatcher, J. B., on the Montana group, 78, 88
Staurolite, 624
Steidtmann, E., *A graphic comparison of the alteration of rocks by weathering with their alteration by hot solutions*, 381
Steuart, D. R., *The shale oil industry of Scotland*, 573
Stevens, H. J., review of book by, 542
Stewart, C. A., discussion by, 536
Stibnite, 614
Stirling, J., discussion by, 534
Stokes, F. N., analysis of paleozoic shales by, 608
Stremme and Späte, on sapropelic rocks, 308
Structure sections, across Illinois, 485
Study of the uranium and vanadium belts of southern Colorado (Fleck and Haldane), review of, 159
Stutzer, O., review of paper by, 545
Sub-bituminous coal, defined, 136, 649
Sullivan, E. C., *Experiments on the separation of the constituents of a solution by filtration through a mineral filter*, 750
Synthesis, of rocks, 711

Table, showing results of coking tests on coals, 268; of sedimentary rocks of Cornwall, 368; of composition of igneous rocks, 401–404; of Cambrian and Ordovician formations of northwestern Virginia, 510; of genetic classification of minerals, 618–622
Teall, J. J. H., on contemporaneous veins, 604
Terneras intrusion, 693
Terneras ore, composition of, 715–719
Test, practical, for coking coals (Pishel), 265
Tests for ores, minerals, and metals of commercial value (McMechen), review of, 437
Texada Island, iron ores of, 278
Thalen-Tiberg magnetometer, 200
Theory and hypothesis, distinction between, 425
Thermal alteration, 407
Thermal water, 501
Thermopolis, Wyo., section of Cloverley formation near, 85
Tin, in China, 129; in Cornwall, 364; alluvial deposits of, in Cornwall, 379; of Pitkäranta, 541
Tin ores, of Cornwall, genesis of, 377
Torbane, Scotland, section at, 586
Torbanehill mineral, 584
Torbanite, 585
Tourmalinization, 376
Transvaal Mines Department, report of the Geological Survey for the year 1906, review of, 653
Trap rocks, 730
Trenton limestone, 42; composition of, 43
Trüstedt, O., review of paper by, 540
Tsin-ling region, China, 118
Turner, H. W., *The ore deposits at Mineral, Idaho*, 492; discussion by, 538

Tuscaloosa formation, 109
Two-feet coal, 595

Uranium and vanadium belts of southern Colorado (Fleck and Haldane), review of, 159

Vancouver Island, iron ores of, 278
Van Hise, C. R., on cobalt-silver ores, 599, 605; on formation of minerals, 611; on ore deposition, 732; on Sangre de Christo Range, 739
Veatch, O., *The kaolins of the Dry Branch region, Ga.*, 109
Veins, quartz-tourmaline, 499; in diabase-gabbro, in Ontario, 601; contemporaneous, 604; in Velardeña district, Mexico, 679
Veinstones, in Cornwall, structure of, 372
Velardeña district, Mexico, Ore-deposits of (Spurr and Garrey), 688
Velardeña district, Mexico, geologic history of, 688
Verschoyle, W. D., on gold mining in China, 11
Vesuvianite, 624
Virginia, physiographic divisions of, 505; sections in, 506; map showing Ordovician outcrops, 508
Virginia, western, Cement materials of (Bassler), 503
Vogelsang, K., on Ta-pa-shan, China, 36
Vogt, J. H. L., on gray copper, 498
Volume of ores, 319

Water, meteoric, 501
Watson, T. L., analysis of red residual clay by, 116; review by, 343
Weathered rocks, average composition of, 399
Weathering, of coal, 137, 647; alteration of rocks by, 381, 399
Weed, W. H., on Kootenai rocks, 79
Weed and Pirsson, on Montana group, 88
Well drilling, in China, 124
Weller, S., on anticlinals in Illinois, 486
Wherry, E. T., *The Newark copper deposits of southeastern Pennsylvania*, 726
White, C. D., on genesis of petroleum, 298
White, D., *Some problems of the formation of coal*, 292
Wilcox formation, 220
Willemite, 622
Williams, J. F., on periodotite in Arkansas, 526
Williams, R. D., review of paper by, 155
Willis, B., *Mineral resources of China*, 1, 118
Willis, B., and Blackwelder, E., on sections, in China, 118
Willmott, A. B., on iron ores, of Ontario, 280, 284
Winchell, A. N., discussion of paper by, 532
Winchell, H. V., discussion by, 425; review by, 433
Wollastonite, 624
Wright, C. W., *The copper deposits of Kasaan Peninsula, Alaska*, 410
Wright, F. E., on hillebrandite, 707; on spurrite, 707

Xenotime, 624

Yacimientos de boratos y otros productos minerales explotables del territorio de los Andes (Reichert), 652
Yang-tzi region, China, 30–36; formations of, 31
Yttrialite, 624

Zincite, 622